NOTES

1. The societal budget constraint represents a synthesis of Lotka stable population growth dynamics with the standard Solow steady-state growth model. The equilibrium population growth rate is the solution to the integral equation of stable population theory given by:

$$1 = \int_0^{\omega} e^{-gx} p(x) m(x) dx \tag{N.1}$$

where m(x) is the female birth rate to women aged x years. The equilibrium capital-labor ratio is the solution to:

$$k = sf(k) - gk \tag{N.2}$$

where k is rate of change in k and s is savings per worker. The comparative-static change in expected lifetime welfare $(\delta W)$ resulting from a change in mortality rates across different ages $(\delta p(x))$ is found by taking the differential across equation (l):

$$\delta W = \int_0^{\omega} U[c(x),x]\delta p(x)dx + \int_0^{\omega} \partial U/\partial c(x) \cdot \delta c[\delta p]p(x)dx. \tag{N.3}$$

Under the assumptions of utility maximization and perfect capital markets the life-cycle consumption pattern is given by:

$$w/at(x) = \partial U/\partial c(0)e^{-gx} \tag{N.4}$$

so that

$$\delta W = \int_0^{\omega} U[c(x),x]\delta p(x)dx + \partial U/\partial c(0) \int_0^{\omega} e^{-gx}\delta c[\delta p]p(x)dx \tag{N.5}$$

The two terms in equation (N.5) can be interpreted as the change in expected lifetime welfare that come from extra years and the value of changes in the consumption pattern needed to accomodate the additional years of living. The change in consumption can be evaluated by taking differentials across the societal budget constraint, yielding:

$$0 = \int_0^\omega e^{-gx}c(x)\delta p(x)dx + \int_0^\omega e^{-gx}\delta c[\delta p]p(x)dx - (f(k)-gk)\int_0^\omega e^{-gx}\lambda(x)\delta p(x)dx$$

$$- \delta k[\delta p](f'-g)\int_0^\omega e^{-gx}\lambda(x)p(x)dx - \beta\delta g[\delta p] \qquad \text{(N.6)}$$

where

$$\beta = \int_0^\omega xe^{-gx}c(x)p(x)dx - (f(k)-gk)\int_0^\omega xe^{-gx}\lambda(x)p(x)dx - k\int_0^\omega e^{-gx}\lambda(x)p(x)dx.$$

$\beta$ is the life-cycle value of a marginal increase in the population growth rate (Arthur and McNicoll, 1978). Following Arthur (1981) this term can be expressed as:

$$\beta = (1/b)\,[\bar{c}(A_C-A_L)-kn] \qquad \text{(N.7)}$$

where b is the crude birth rate in the stable population $\bar{c}$ is per capita consumption, $A_C$ and $A_L$ are the average ages of consumption and production, respectively, and n is the labor/population ratio. Using equation (N.6) to substitute for the second term in equation (N.5) results in the expression for the change in lifetime welfare given by equation (3) in the text.

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Valuing Nonmarket Goods:
A Household Production Approach*

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## ABSTRACT

This paper presents a unique application of the household production approach to valuing public goods and nonmarket commodities. Technical relationships are estimated between health attributes, private goods that affect health, and air quality using panel data drawn from a special survey. Statistical tests show that individuals equate marginal rates of technical substitution in household production with relevant price ratios. This result confirms theoretical implications in a particularly critical context for estimating values of health attributes and air pollution. Value estimates obtained also bear on current questions facing environmental policymakers.

## I. Introduction

Individuals frequently apply a household technology to combine public and private goods in the production of nonmarket commodities for final consumption. Hori (1975) demonstrates that in these situations, market prices of private goods together with production function parameters may encode enough information to value both public goods used as inputs and nonmarket final consumption commodities. Although this valuation methodology is objective and market based, it seldom has been applied for three reasons. First, underlying technical relations either are unknown or data needed to estimate them are unavailable. Second, even if relevant technical information is at hand, the consumer's budget surface in commodity space may not be differentiable when joint production and other complicating factors are present. As a consequence, the commodity bundle chosen is consistent with any number of marginal rates of substitution and sought after values of public goods and nonmarket commodities remain unknown. Third, joint production and nonconstant returns to scale also pose serious difficulties when taking the closely related valuation approach' of estimating the area behind demand curves for private goods inputs and final consumption commodities Pollak and Wachter 1975; Bockstael and McConnell 1983).

This paper presents a unique application of the household production approach to valuing public goods and nonmarket commodities which allows for certain types of joint production and addresses key problems identified by previous authors. Technical relationships are estimated between health attributes, private goods, and air quality. Data used in the analysis are drawn from a special survey designed to implement the household production approach. Econometric estimates allow for truncated dependent variables in panel data using tobit models with individual-specific variance components. Key results are: (1) attempts to value detailed attributes of nonmarket home produced commodities may be ill-advised; however, estimating a common value for a broadly defined category of attributes may be possible, and (2) statistical tests show that individuals equate marginal rates of technical substitution in household production with relevant price ratios. This latter result confirms behavioral implications of the theory in a particularly critical context for estimating values of nonmarket commodities and public goods. Also, value estimates obtained bear on current questions concerning air pollution control policy. The Clean Air Act of 1970 and its subsequent amendments focus exclusively on health to justify regulation and requires air quality standards to protect even the health of those most sensitive to pollution. The survey data are sufficiently rich to allow separate value estimates for persons with normal respiratory function and persons with chronic respiratory impairments.

The remainder of this paper is divided into four sections. Section II describes a simple household production model in a health context and reviews theoretical issues in obtaining value estimates. Section III discusses the survey instrument and the data collected. Section IV presents econometric estimates of production functions for health attributes, as well as values of better air quality and improved health for both the normal and respiratory impaired subsamples. Implications and conclusions are drawn out in Section V.

## II. PRELIMINARIES

The model specifies utility (U) as a function of market goods (Z) and health attributes, called symptoms, (S).

$$U = U(Z, S) \tag{1}$$

For simplicity, Z is treated as a single composite good, but S denotes a vector measuring intensity of n health symptoms such as shortness of breath, throat irritation, sinus pain, headache, or cough. Intensity of the $i^{th}$ symptom is reduced using a vector (V) of m additional private goods that do not yield direct utility, a vector of ambient air pollution concentrations (a), and an endowment of health capital ($\Omega$).

$$S^i = S^i(V, a; \Omega) \qquad i=1, \ldots, n \tag{2}$$

Elements of V represent goods an individual might purchase to reduce intensity of particular symptoms, and $\Omega$ represents genetic predisposition to experience symptoms or presence of chronic health conditions that cause symptoms. Notice that equation (2) allows for joint production in that some or all elements of V may (but do not necessarily) enter some or all symptom production functions.[1] The budget constraint is

$$I = P_Z Z + \Sigma_j P_j V_j \tag{3}$$

where $P_Z$ denotes the price of Z, $P_j$ denotes the price of $V_j$, and I denotes income.

Aspects of this general approach to modeling health decisions have been used in the health economics literature (e.g., Grossman 1972; Rosenzweig and Schultz 1982, 1983), where medical care is an example of V often considered. In these three papers, however, the stock of health rather than symptoms is treated as the home produced good, and Grossman treats decision making intertemporally in order to analyze changes in the health stock over time. A multiperiod framework would permit a more complete description of air pollution's cumulative physiological damage, but the present model's focus on symptoms of short duration, suggests that a one period model is appropriate. Moreover, long term panel data containing both economic and health information necessary to assess cumulative physiological damage are difficult to obtain.

Similar models also have been used in environmental economics to derive theoretically correct methods for estimating values of air quality and other environmental attributes (e.g., Courant and Porter 1981; Harford 1984; Harrington and Portney 1987). These models, however, only consider the case in which m = n = 1 and rule out the possibility of joint production. In this situation, the marginal value of or willingness to pay (WTP) for a reduction in air pollution can be derived by setting dU = 0 and using first order conditions to obtain

$$WTP_{\alpha} = - U_1 S^1_{\alpha}/\lambda = - P_1 S^1_{\alpha}/S^1_1 \qquad (4)$$

where $U_1$ denotes marginal disutility of the symptom, $S^1_{\alpha}$ denotes the marginal effect of air pollution on symptom intensity, $S^1_1$ denotes the marginal product of $V_1$ in reducing symptom intensity, and $\lambda$ denotes marginal utility of income. As shown, marginal willingness to pay to reduce symptom intensity $(- U_1/\lambda)$ equals the marginal cost of doing so $(- P_1/S^1_1)$.

Extensions to situations where m and n take on arbitrary values have been considered in the theory of multi-ware production by Frisch (1965) as well as in a public finance context by Hori (1975). Actually, Hori treats four types of household production technology. His case (3) involving joint production appears to best characterize the application discussed in Section IV because a single $V_j$ may simultaneously reduce more than one symptom. In this situation, a key result is that marginal values of symptom intensity $(- U_i/\lambda)$ cannot be re-expressed in terms of market prices $(P_j)$ and production function parameters $(S^i_j)$ unless the number of private goods is at least as great as the number of symptoms $(m \geq n)$. Intuitively, if $m < n$, the individual does not have a choice among some alternative combinations of symptom intensities because there are too few choice variables $(V_j)$ and the budget surfaces on which each chosen value of $S^i$ must lie is not differentiable. [2]

Another perspective on this result can be obtained from the m first order equations for the $V_j$ shown in (5)

$$\begin{bmatrix} S_1^1 & \cdots & S_1^n \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ S_m^1 & \cdots & S_m^n \end{bmatrix} \begin{bmatrix} U_1/\lambda \\ \cdot \\ \cdot \\ \cdot \\ U_n/\lambda \end{bmatrix} = \begin{bmatrix} P_1 \\ \cdot \\ \cdot \\ \cdot \\ P_m \end{bmatrix} \tag{5}$$

Each first order condition holds as an equality provided each private good is purchased in positive quantities. If $m < n$ the rank of the symptom technology matrix $S = \{S_j^i\}$ is at most m, the system of equations in (5) is underdetermined, intensity of one symptom cannot be varied holding others constant, and the marginal value of an individual symptom cannot be determined. On the other hand, if $m = n$ and the symptom technology matrix is nonsingular, then the rank is n and unique solutions can be computed for the $U_i/\lambda$. If $m > n$ and the technology matrix has full rank, then the system is overdetermined, and values for the $U_i/\lambda$ can be computed from a subset of the first order equations.

Solving (5) computes marginal values for the nonmarket commodities produced by the individual. The value of the public good input, $\alpha$, is the weighted sum of the value of the commodities, where the weights are the marginal products of $\alpha$ in reducing symptoms: $WTP_\alpha = -\Sigma_i(U_i/\lambda)S_{i\alpha}$. If the marginal products of a are known or estimated, solving (5) provides the information necessary to value nonmarket commodities and public goods.

This theoretical overview yields several ideas useful in empirical application. First, if $m \geq n$ and the household technology matrix has rank n, then values of nonmarket commodities and public goods are calculated in a relatively straightforward manner because utility terms can be eliminated. Second, even in cases where $m \geq n$, the household production approach may fail if there is linear dependence among the rows of the technology matrix. Thus, statistical tests of the rank of the matrix should be performed to ensure differentiability of the budget surface. Third, if $m > n$, first order conditions impose constraints on values that can be taken by the $S_j^i$; validity of these constraints can be tested. Fourth, the possibility that $m < n$ suggests that the household production approach may be incapable of estimating separate values for a comparatively large number of detailed commodities and that aggregation of commodities may be necessary to ensure $m > n$.[3]

Fifth, if $m > n$, values of $S_j^i$ and $P_j$ need not yield positive values for $-U_i/\lambda$, the marginal willingness to pay to reduce intensity of the $i^{th}$ symptom. Of course, in the simple case where $m = n = 1$, the only requirement is that $-P_1/S_1^1 > 0$. If $m = n = 2$, a case considered in the empirical work presented in Section IV, values of $-U_1/\lambda$ and $-U_2/\lambda$ both will be positive only if $(S_1^1/S_2^1) \gtrless (P_1/P_2) \gtrless (S_1^2/S_2^2)$. If $V_1$ and $V_2$ are not chosen such that their marginal rates of technical substitution bracket their price ratio, then it is possible to reduce intensity of one symptom without increasing intensity of the other and without spending more on symptom reduction.

Sixth, complications arise in expressing symptom and air pollution values in situations where some or all of the $V_i$ are sources of direct utility, a form of joint production. This problem is important (and it is encountered in the empirical work presented in Section IV) because of the difficulty in identifying private goods that are purchased but do not enter the utility function. To illustrate, assume that m = 2, n = 1 and that $V_2$ but not $V_1$ is a source of both direct positive utility and symptom relief. $WTP_\alpha$ still would equal $-(P_1 S_\alpha^1/S_1^1)$ and therefore could be calculated without knowing values for marginal utility terms. If consumption of $V_2$, however, was used as a basis for this calculation, the simple formula $-(P_2 S_\alpha^1/S_2^1)$ would overestimate $WTP_\alpha$ by an amount equal to $-(U_2 S_\alpha^1/\lambda S_2^1)$ where $U_2$ denotes marginal utility of $V_2$ ($U_2 > 0$). When m and n take arbitrary values, the situation is more complex, but in general nonmarket commodity and public good values can be determined only if the number of private goods which do not enter the utility function is at least as great as the number of final commodities. Even if this condition is not met, however, it is possible in some cases to determine whether the value of nonmarket commodities and public goods is over- or underestimated.[4]

## III. DATA

Data used to implement the household production approach were obtained from a sample of 226 residents of two Los Angeles area communities. Each respondent previously had participated in a study of chronic obstructive respiratory disease (Detels et al. 1979, 1981). Key aspects of this sample are: (1) persons with physician diagnosed chronic respiratory ailments deliberately are overrepresented (76 respondents suffered from such diseases), (2) 50 additional respondents with self-reported chronic cough or chronic shortness of breath are included, (3) 151 respondents lived in Glendora, a community with high oxidant air pollution, and 75 respondents lived in Burbank, a community with oxidant pollution levels more like other urbanized areas in the U.S. but with high levels of carbon monoxide, (4) all respondents either were nonsmokers or former smokers who had not smoked in at least two years, and (5) all respondents were household heads with full-time jobs (defined as at least 1,600 hours of work annually).

Professionally trained interviewers contacted respondents several times over a 17 month period beginning in July 1985. The first contact involved administration of an extensive baseline questionnaire in the respondent's home. Subsequent interviews were conducted by telephone.[5] Including the baseline interview, the number of contacts with each respondent varied from three to six with an average number of contacts per respondent of just over five. Of the 1147 total contacts ($\approx$ 226 x 5), 644 were with respiratory impaired subjects (i.e., those either with physician-diagnosed or self-reported chronic respiratory ailments) and 503 were with respondents having normal respiratory function.

Initial baseline interviews measured four groups of variables: (1) long term health status, (2) recently experienced health symptoms, (3) use of private goods and activities that might reduce symptom intensity, and (4) socioeconomic/demographic and work environment characteristics. Telephone follow-up interviews inquired further about health symptoms and use of particular private goods. Long term health status was measured in two ways. First, respondents indicated whether a physician ever had diagnosed asthma (ASTHMA), chronic bronchitis (BRONCH), or other chronic respiratory disease such as emphysema, tuberculosis, or lung cancer

(OTHDIS). Second, they stated whether they experience chronic shortness of breath or wheezing (SHRTWHZ) and/or regularly cough up phlegm, sputum, or mucous (FLEMCO). Respondents also indicated whether they suffer from hay fever (HAYFEV); however, this condition was not treated as indicative of a chronic respiratory impairment.

Both background and follow-up instruments also asked which, if any, of 26 health symptoms were experienced in the two days prior to the interview. Symptoms initially were aggregated into two categories defined as: (1) chest and throat symptoms and (2) all other symptoms.[6] Aggregation to two categories reduces the number of household produced final goods (n) considered; however, assigning particular symptoms to these categories admittedly is somewhat arbitrary. Yet, the classification scheme selected permits focus on a group of symptoms in which there is current policy interest. Chest and throat symptoms identified have been linked to ambient ozone exposure (see Gerking et al. 1984, for a survey of the evidence) and federal standards for this air pollutant currently are under review. Moreover, multivariate tobit turns out to be a natural estimation method and aggregating symptoms into two categories permits a reduction in computation burden. Dickie et al. (1987(a)) report that respondents with chronic respiratory impairments experienced <u>each</u> of the 26 individual symptoms more often than respondents with normal respiratory function. This outcome is reflected in Table 1 which tabulates frequency distributions of the total number of chest and throat and other symptoms reported by respondents in the two subsamples.[7]

In the empirical work reported in Section IV, data on the number of symptoms reported are assumed to be built up from unobserved latent variables measuring symptom intensity. As intensity of a particular symptom such as cough rises above a threshold, the individual reports having experienced it; otherwise he does not. Thus, the frequency distribution tabulated in Table 1 merely reflects the number of symptoms that crossed the intensity threshold in the two days prior to the interview.

Private goods which indicated steps taken in the past that might reduce symptoms over a period of years, measured whether the respondent has and uses: (1) central air conditioning in the home (ACCEN), (2) an air purifying system in the home, (3) air conditioning in the automobile (ACCAR), and (4) a fuel other than natural gas for cooking (NOTGASCK).[8] These variables represent goods that may provide direct sources of utility to respondents. Air conditioners, for example, not only may provide relief from minor health symptoms; but also provide cooling services that yield direct satisfaction. This problem is discussed further in Section V.

Socioeconomic/demographic variables measured whether the respondent lived in Burbank or Glendora (BURB) as well as years of age (AGE), gender, race (white or nonwhite), marital status, and household income. Also, respondents were asked whether they were exposed to toxic fumes or dust while at work (EXPWORK).

Finally, each contact with a respondent was matched to measures of ambient air pollution concentrations, humidity, and temperature for that day. Air monitoring stations used are those nearest to residences of respondents in each of the two communities. Measures were obtained of the six criteria pollutants for which national ambient air quality standards have been established: carbon monoxide (CO), nitrogen dioxide (NO2), ozone (03), sulfur dioxide (S02), lead and total suspended particulate. Readings for lead and particulate, however, only were available for about ten percent of the days during the study period, forcing exclusion of those pollutants from empirical work. Each of the remaining four pollutants were measured as maximum daily one-hour ambient concentrations. Maxima are used because epidemiological and medical evidence suggests that acute symptoms may be more closely related to peak than to average pollution concentrations. The air pollution variables entered then, are averages of one hour maxima on the two days prior to the interview so as to conform with the measurement of symptoms.[9] Temperature and relative humidity data similarly were averaged across two day periods.

## IV. ESTIMATES OF HOUSEHOLD SYMPTOM TECHNOLOGY

This section reports estimates of production functions for chest and throat and other symptoms. Empirical estimates of household production technology in a health context also have been obtained by Rosenzweig and Schultz (1983); however, these investigators consider determinants of birth weight rather than health symptoms and do not focus on valuing nonmarket commodities and public goods.[10] The symptom production functions reported below are estimated in a bivariate tobit framework with variance components.[11] Bivariate tobit estimation was performed because of the probable correlation between disturbances across equations. Given that symptoms often appear in clusters, individuals reporting symptoms in one category may also report them in the other. Also, as noted in the discussion of Table 1, the modal number of symptoms reported was zero.

Random disturbances follow an error components pattern, consisting of the sum of a permanent and a transitory component.

$$\varepsilon_{iht} = \mu_h + \upsilon_{iht} \qquad i = R, N \tag{6}$$

where i denotes type of symptom (chest and throat, other), h denotes respondent, and t denotes time. The transitory error component, $\upsilon_{iht}$, captures unmeasured effects that vary over individuals, symptoms, or time. The permanent error component $\mu_h$, in contrast, varies only over individuals; for a given individual it is constant over time and common to production functions for both types of symptoms. The permanent error component serves two purposes in the model. First, it captures persistent unmeasured but individual specific factors that influence symptoms, including unmeasured elements of $\Omega$ and/or the threshold at which symptoms are reported. Hence, $\mu_h$ exerts an independent influence by allowing individuals with identical measured characteristics to have different numbers of symptoms. Second, a given individual's permanent error component captures contemporaneous correlation between the two symptom classes.

The $\mu_h$ are assumed to be independent drawings from identical distributions. Mundlak (1978) and others have argued that the $\mu_h$ are likely to be correlated with values of the explanatory variables, and the error components. For example, if an individual knows his own $\mu_h$, then utility maximization would imply that his choice of private goods depends on $\mu_h$. A possible solution would be to replace the random effects with fixed effects in which the $\mu_h$ are assumed to be constants that vary across individuals. Mundlak notes, however, that the fixed effects model suffers from a serious defect if $\mu_h$ is correlated with some or all covariates: It is impossible to distinguish between the effects of time invariant covariates and the fixed effects. This defect of the fixed effects model is troublesome, because all covariates except the air pollution measures are time invariant. Since the valuation procedure of Section 2 requires distinguishing marginal products of private goods from the individual's predisposition to illness, the fixed effects model was rejected in favor of random effects.

Both transitory and permanent error components are assumed normally distributed with $E(\mu_h) = 0$, $E(\mu_h^2) = \sigma_\mu^2$, and $E(\mu_h \mu_{h'}) = 0$ for $h \neq h'$; $E(\upsilon_{iht}) = 0$, $E(\upsilon_{iht}^2) = \sigma_\upsilon^2$, and $E(\upsilon_{iht}\upsilon_{i'h't'}) = 0$ for $i \neq i'$ or $h \neq h'$ or $t \neq t'$. The permanent error component is distributed independently of the transitory error component, so the distribution of the summed error components is normal with $E(\varepsilon_{iht}) = 0$, $E(\varepsilon_{iht}^2) = \sigma_\mu^2 + \sigma_\upsilon^2$, and $E(\varepsilon_{iht}\varepsilon_{iht'}) = \sigma_\mu^2 = E(\varepsilon_{Rht}\varepsilon_{Nht})$.

Given $\mu_h$ and the distributional assumptions about the error components, the likelihood for the $h^{th}$ individual is the product of independent tobit likelihoods: one tobit for each symptom class in each time period. The conditional likelihood for the $h^{th}$ individual is

$$L_h(\mu_h) = \prod_{S_{Rt}>0} f(\upsilon_{Rt}|\mu) \prod_{S_{Rt}=0} F(\upsilon_{Rt}|\mu) \prod_{S_{Nt}>0} f(\upsilon_{Nt}|\mu) \prod_{S_{Nt}=0} F(\upsilon_{Nt}|\mu) \qquad (7)$$

where $f(\cdot)$ is the normal density and $F(\cdot)$ is the normal distribution. Conditioning was removed by integrating over $\mu$. In order to address the problem of an unequal number of interviews per respondent, log-likelihood values first were computed for each respondent, and then summed to obtain totals.[12]

Tables 2 and 3 present illustrative symptom production function estimates for the impaired and normal subsamples. Equations presented are representative of a somewhat broader range of alternative specifications that are available from the authors on request. Alternative specifications included attempts to correct for simultaneity between symptoms and private goods. Bartik (1988) calls attention to this problem in a related context and Rosenzweig and Schultz treat it in their previously cited birthweight study. Procedures devised for the present study are analogous to two-stage least squares. In the first stage, reduced form probit demand equations for each of four private goods (ACHOME, ACCAR, APHOME, NOTGASCK)[13] were estimated. In the second stage, predicted probabilities from the reduced form probits were to be used as instruments for private goods in the tobit symptom production function models. However, explanatory power of the reduced form probit equations was very poor. In half of the equations for each subsample the null hypothesis that all slope coefficients jointly are zero could not be rejected at the 5 percent level and in all equations key variables such as household income had insignificant and often wrongly signed coefficients. Another problem is the absence of private good price data specific to each respondent. The original survey materials requested these data but after pretesting, this series of questions was dropped because many respondents often made purchases jointly with a house or car and were unable to provide even an approximate answer. As a consequence, simultaneous equation estimation was not pursued further with the likely outcome that estimates of willingness to pay for nonmarket commodities and public goods may have a downward bias.[14]

In any case, one result of interest from the bivariate tobit estimates in Tables 2 and 3 is the outcome of testing the null hypothesis that estimated symptom production parameters jointly are zero. In the four equations reported, a likelihood ratio test rejects this hypothesis at significance levels less than 1 percent. Also, estimates of the. individual specific error components, denoted $\sigma_\mu$, have large asymptotic t-statistics which confirms persistence of unobserved personal characteristics that affect symptoms.

Table 2 shows that chronic health ailments and hay fever are positively related to symptom occurrence among members of the impaired group. Coefficients of ASTHMA, BRONCH, SHRTWHZ, and HAYFEV are positive in equations for both chest and throat and other symptoms and have associated asymptotic t-statistics that range from 2.1 to 7.6. The coefficient of FLEMCO is positive and significantly different from zero at conventional levels in the chest and throat equation, but its asymptotic t-statistic is less than unity in the equation for other symptoms. The coefficient of AGE was not significantly different from zero in either equation and the EXPWORK variable was excluded because of convergence problems with the bivariate tobit algorithm.[15] Variables measuring gender, race, and marital status never were included in the analysis because 92 percent of the impaired respondents were male, 100 percent were white, and 90 percent were married. Residents of Burbank experience chest and throat symptoms with less frequency than do residents of Glendora. Of course, many possible factors could explain this outcome; however, Burbank has had a less severe long term ambient ozone pollution problem than Glendora. For example, in 1986 average one day hourly maximum ozone readings in Burbank and Glendora were 8.7 pphm and 10.2 pphm, respectively.

With respect to private and public inputs to the symptom production functions, the coefficient of ACCAR is negative and significantly different from zero at the 10 percent level using a one tail test in the other symptoms equation, while the coefficient of ACCEN is negative and significantly different from zero at the 5 percent level using a one tail test in both equations. Results from estimated equations not presented reveal that NOTGASCK and use of air purification at home never are significant determinants of symptoms in the impaired subsample. Also, 03, CO, and NO2 exert insignificant influences on occurrence of both types of symptoms. When four air pollution variables were entered, collinearity between them appeared to prevent the maximum likelihood algorithm from converging. Consequently, SO2 was arbitrarily excluded from the specification presented and the three air pollution measures included as covariates should be interpreted as broader indices of ambient pollutant concentrations. Variables measuring temperature and humidity were excluded from the Table 2 specification; but in equations not reported their coefficients never were significantly different from zero.

Table 3 presents corresponding symptom production estimates for the subsample with normal respiratory function. HAYFEV is the only health status variable entered because ASTHMA, BRONCH, SHRTWZ, and FLEMCO were used to define the impaired subsample. Coefficients of HAYFEV are positive in equations for both chest and throat and other symptoms and have t-statistics of 1.61 and 1.87, respectively. Coefficients of BURB are negative; but in contrast to impaired subsample results, they are not significantly different from zero at conventional levels. AGE and EXPWORK enter positively and their coefficients differ significantly from zero at 2½ percent in the other symptoms equation. Among private goods entering the production functions, coefficients of APHOME and ACHOME never were significantly different from zero at conventional levels, and these variables are excluded from the specification in Table 3. Use of air conditioning in an automobile reduced chest and throat symptom occurrences and cooking with a fuel other than natural gas (marginally) reduces other symptoms. Variables measuring gender, race, and marital status again were not considered as the normal subsample was 94 percent male, 99 percent white, and 88 percent married. In the normal subsample, collinearity and algorithm convergence problems again limited the number of air pollution variables that could be entered in the same equation. As shown in Table 3, when O3, CO, and NO2, coefficients had associated t-statistics of 1.16 or smaller. Temperature and humidity variables are excluded from the specification shown in Table 3. In alternative specifications not reported, coefficients of these variables never were significantly different from zero in alternative equations not reported.

Three pieces of information are required to use the estimates in Tables 2 and 3 in the calculation of values for nonmarket commodities (the two types of symptoms) and public goods (air pollutants): (1) marginal effects of air pollutants on symptoms, (2) marginal effects of private goods on symptoms, and (3) prices of private goods. Marginal products were defined as the effect of a small change in a good on the expected number of symptoms. Computational formulae were developed extending results for the tobit model (see McDonald and Moffit 1980) to the present context which allows for variance components error structure. However, because private goods are measured as dummy variables and, therefore, cannot be continuously varied, incremental, rather than marginal, products are used.

The final elements needed to compute value estimates are the prices of private goods. Dealers of these goods in the Burbank and Glendora areas were contacted for estimates of initial investment required to purchase the goods, average length of life, scrap value (if any), and fuel expense. After deducting the present scrap value from the initial investment, the net initial investment was amortized over the expected length of years of life. Adding annual fuel expense yields an estimate (or range of estimates) of annual user cost of the private good. The annual costs then were converted to two-day costs to match the survey data.[16] The dependent variables used in the estimated equations do not distinguish between one- and two-day occurrences of symptoms, but approximately one-half of the occurrences were reported as two day occurrences. As a consequence, the value estimates obtained were divided by 1.5 to convert to daily values.

Two tests were performed prior to estimating values of symptom and air pollution reduction. First, calculations were made for both normal and impaired subsamples to ensure that relevant ratios of incremental products of private goods in reducing symptoms bracketed the corresponding price ratio. Recall from the discussion in Section 2 that this condition guarantees that value estimates for reducing both types of symptoms are positive. A problem in making this calculation is that estimates of incremental rates of technical substitution vary across individuals (incremental products are functions of individual characteristics), but no respondent specific price information is available. As just indicated, dealers in Glendora provided the basis for a plausible range of prices to be constructed for each good. If midpoints of relevant price ranges are used together with incremental rates of technical substitution taken from Tables 2 and 3, the bracketing condition is met for all 100 respondents in the normal subsample and 117 of 126 respondents in the impaired subsample. Of course, alternative price ratios selected from this range meet the bracketing condition for different numbers of respondents.

Second, possible singularity of the symptom technology matrix was analyzed using a Wald test (see Judge et al. 1985, p. 215 for details).[17] In the context of estimates in Tables 2 and 3, the distribution of the test statistic ($\lambda$) is difficult to evaluate because relevant derivatives are functions of covariate values and specific to individual respondents. However, if derivatives are evaluated in terms of the underlying latent variable model, they can be expressed in terms of only parameters and $\lambda$ is distributed as $\chi^2$ with 1 degree of freedom. Adopting this simpler approach, p-values for the Wald test statistic are large: p = .742 for the impaired subsample equations and p = .610 for the normal subsample equations.[18] As a consequence, the null hypothesis of singularity of the symptom technology matrix is not rejected at conventional levels. This result suggests that in both subsamples, there does not appear to be an independent technology for reducing the two types of symptoms, budget constraints are nondifferentiable, and separate value estimates for chest and throat and ocher symptoms should not be calculated.

A common value for reducing chest and throat and other symptoms still can be obtained by aggregating the two categories and re-estimating production functions in a univariate tobit framework. Table 4 shows results based on using the same covariates as those reported in Tables 2 and 3 and retaining the variance components error structure. The Table 4 equations also make use of a constraint requiring that if m > n = 1, values of marginal willingness to pay to avoid a symptom must be identical no matter which private good is used as the basis for the calculation. In the case where m = 2 and n = 1, as discussed in Section II, this single value is $-U_1/\lambda = -(P_1/S_1^1) = -(P_2/S_2^1)$. In the impaired subsample, the restriction can be tested under the null hypothesis, $H_0 : \beta_{ACCAR} = (P_{ACCAR}/P_{ACHOME})\beta_{ACHOME}$, where the $\beta_i$ are coefficients of ACCAR and ACHOME in the latent model and the $P_i$ are midpoints from the estimated range of two day prices for the private goods. In corresponding notation, the null hypothesis to test in the normal subsample is, $H_0 : \beta_{ACCAR} = (P_{ACCAR}/P_{NOTGASCK})\beta_{NOTGASCK}$. Both hypotheses are tested against the alternative that coefficients of private goods are unconstrained parameters.

P-values for the parameter restrictions are comparatively large; P = .623 in the impaired subsample and P = .562 in the normal subsample. Thus, the above null hypotheses are not rejected at conventional significance levels. Respondents appear to equate marginal rates of technical substitution in production with relevant price ratios; a result that supports a critical implication of the previously presented household production model. Moreover, coefficients of private good variables defined under the null hypotheses for the two subsamples have t-statistics exceeding two in absolute value. Performance of remaining variables is roughly comparable to the bivariate tobit estimates. A notable exception, however, is that in the normal subsample univariate tobit estimates, coefficients of $O_3$ and $NO_2$ are positive with t-statistics exceeding 1.6. This outcome suggests that persons with normal respiratory function tend to experience more symptoms when air pollution levels are high, whereas those with impaired respiratory function experience symptoms with such regularity that there is no clear relationship to fluctuations in air quality. Intensity of particular symptoms may be greater in both subsamples when pollution levels are high, but this aspect is not directly measured.

Table 5 presents estimates of marginal willingness to pay to avoid symptoms to reduce two air pollutants. Unconditional values of relieving symptoms and reducing air pollution are calculated for each respondent from observed univariate tobit models. Table 5 reports the mean, median, and range of respondents' marginal willingness to pay to eliminate one health symptom for one day as well as mean marginal willingness to pay to reduce air pollutants by one unit for one day for the normal subsample. Symptom reduction values range from \$0.81 to \$1.90 in the impaired subsample and from \$0.49 to \$1.22 in the normal subsample with means of \$1.12 and \$0.73 in the two subsamples, respectively.[19] Also, values of willingness to pay to reduce one hour daily maximum levels of $O_3$ and $NO_2$ by one part per million are \$0.31 and \$0.91 in the normal subsample. Corresponding calculations are not reported for the impaired subsample because, as shown in Table 4, coefficients of air pollution variables are not significant at conventional levels.

## V. CONCLUSION

Willingness to pay values of symptom reduction and air quality improvement just presented should be viewed as illustrative approximations for two reasons. First, private goods used in computing the estimates are likely to be direct sources of utility. Second, symptom experience and private good purchase decisions are likely to be jointly determined. Nevertheless, these estimates still are of interest because aspects of joint production are taken into account. A key finding is that independent technologies for home producing symptoms are difficult to identify, thus greatly limiting the number of individual symptoms for which values can be computed. In fact, the 26 symptoms analyzed here had to be aggregated into a single group before willingness to pay values could be computed.

This outcome appears to have implications for estimating willingness to pay for nonmarket commodities in other contexts. An obvious example concerns previous estimates of willingness to pay to avoid health symptoms. Berger et al. (1987) report one day willingness to pay values for eliminating each of seven minor health symptoms, such as stuffed up sinuses, cough, headache and heavy drowsiness that range from \$27 per day to $142 per day. Green et al. (1978) present estimates of willingness to pay to avoid similarly defined symptoms ranging from $26 per day to $79 per day. In both studies, however, willingness to pay estimates were obtained symptom by symptom in a contingent valuation framework that ignores whether independent technologies are available to produce each. Thus, respondents simply may have lumped total willingness to pay for broader health concerns onto particular symptoms. Some respondents may also have inadvertently stated their willingness to pay to avoid symptoms for periods longer than one day.

Another example relates to emerging research aimed at splitting willingness to pay to reduce air pollution into health, visibility, and possibly other components. From a policy standpoint, this line of inquiry is important because the Clean Air Act and its subsequent amendments focus exclusively on health and give little weight to other reasons why people may want lower air pollution levels. Analyzing location choice within metropolitan areas, for example, may not provide enough information to decompose total willingness to pay into desired components. Instead, survey procedures must be designed in which respondents are either reminded of independent technologies that can be used to home produce air pollution related goods or else confronted with believable hypothetical situations that allow one good to vary while others are held constant.

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# ENDNOTES

1. Another, possibly troublesome, aspect of joint production occurs if some or all elements of V are arguments in the utility function. This complication is discussed momentarily.
2. Hori identifies three sources of nondifferentiability of the budget surface under joint production. The first occurs if the number of private goods is less than the number of commodities. The second arises because of nonnegativity restrictions on the private goods. This is not treated directly in the present paper, but if each private good is purchased in positive quantities, the chosen commodity bundle will not lie at the second type of kink. Hori's third cause of nondifferentiability implies linear dependence among the rows of the technology matrix.
3. Notice that this point on aggregation may apply to other valuation methods as well. Using contingent valuation surveys, for example, Green et al. (1978) and Berger et al. (1987) obtained value estimates of several specific symptoms; however, issues relating to existence of independent symptom technologies never was faced. Future contingent valuation surveys may do well to consider this point prior to eliciting estimates of willingness to pay.
4. For example, suppose m = n = 2 and both private goods are direct sources of utility. If equation (6) is used to solve for the $U_i/\lambda$, then: (1) if the two marginal rates of technical substitution (MRTS) do not bracket the price ratio, then the value of the commodity whose

MRTS is closer in magnitude to the price ratio will be overestimated, while the value of the other commodity will be underestimated; (2) if the two MRTS values do bracket the price ratio, then the value of either one or both of the commodities will be overestimated; and (3) in no case will the value of both commodities be underestimated.

5. Both questionnaires are presented and extensively discussed in Volume II of Dickie et al. (1987(b)).

6. Chest and throat symptoms include (1) cough, (2) throat irritation, (3) husky voice, (4) phlegm, sputum or mucous, (5) chest tightness, (6) could not take a deep breath, (7) pain on deep respiration, (8) out of breath easily, (9) breathing sounds wheezing or whistling. Other symptoms are (1) eye irritation, (2) could not see as well as usual, (3) eyes sensitive to bright light, (4) ringing in ears (5) pain in ears, (6) sinus pain, (7) nosebleed, (8) dry and painful nose, (9) runny nose, (10) fast heartbeat at rest, (11) tired easily, (12) faintness or dizziness, (13) felt spaced out or disoriented, (14) headache, (15) chills or fever, (16) nausea, and (17) swollen glands.

7. An alternative to counting the number of different symptoms experienced in the two days prior to the interview would be to consider the number of symptom/days experienced. Both approaches were used to construct empirical estimates; however, to save space, only those based on counts of different symptoms are reported. Both approaches yield virtually identical value estimates for symptom and air pollution reduction.

8. The first three private goods reduce exposure to air pollution by purifying and conditioning the air. The fourth reduces exposure because gas stoves emit nitrogen dioxide.

9. The equations also were estimated after defining the pollution variables as the largest of the one hour maxima on the two days; similar results were obtained.

10. Rosenzweig and Schultz also initially specify their production functions in translog form and then test whether restrictions to CES and Cobb-Douglas forms are justified. This type of analysis is not pursued here as most of the covariates used are 0-1 dummy variables. Squaring these variables does not alter their values. Interaction variables of course, still could be computed.

11. Although there is a linear relationship between the latent dependent variables and the private goods in the tobit model, the relationship between the observed dependent variables and the private goods has the usual properties of a production function. The expected number of symptoms is decreasing and convex (nonstrictly) in the private goods.

12. The tobit coefficients and variances of the model are estimated by maximizing the likelihood function using the method of Berndt, Hall, Hall, and Hausman (1974). The score vectors are specified analytically and the information matrix is approximated numerically using the summed outer products of the score vectors. Starting values for the coefficients and the standard deviations of the transitory error components were obtained from two independent tobit regressions with no permanent error component. In preliminary runs a starting value of unity was used for the standard deviation of the permanent error component, but the starting value was adjusted to 1.5 after the initial estimate was consistently greater than one.

13. Covariates in the reduced form regressions are: ASTHMA, BRONCH, FLEMCO, SHRTWZ, HAYFEV, BURB, AGE, EXPWORK, years of education, number of dependents, household income, and an occupation dummy variable measuring whether respondent is a blue collar worker.

14. An alternative to the two-stage procedure was suggested by Chamberlain (1980) for random effects probit models. Chamberlain's approach uses information from temporal variation in choice variables to distinguish between production function parameters and the parameters of an assumed linear correlation between choice variables and the permanent error component. The approach is not well-suited to the present study because of the lack of temporal variation in the private goods.

15. In the impaired subsample, inclusion of EXPWORK frequently caused the bivariate tobit algorithm to fail to converge. This problem arose in the specification presented in Table 2; consequently the EXPWORK variable was excluded.

16. The estimated two-day prices are: $2.34 for ACCEN, $1.00 for ACCAR, $0.80 for NOTGASCK. The discount rate was assumed to be 5 percent. For further details of the procedure used to estimate prices, see Dickie et al. (1987(a)).

17. The Wald test was chosen because its test statistic can be computed using only the unconstrained estimates. Since the likelihood and constraint functions both are nonlinear, reestimating the model with the constraint imposed would be considerably more difficult than computing the Wald test statistic.

18. In other estimates of symptom production functions not reported here, corresponding p-values also are large, almost always exceeding .25 and sometimes the .80-.90 range.

19. For comparison purposes, mean values also were estimated at subsample means of all explanatory variables. Results differ little with means computed over respondents. Evaluated at subsample means, willingness to pay to eliminate one symptom for one day is $1.05 in the impaired subsample and $0.70 in the normal subsample.

TABLE 1

FREQUENCY DISTRIBUTIONS OF SYMPTOMS BY SUBSAMPLE

| | NUMBER OF CHEST AND THROAT SYMPTOMS EXPERIENCED IN PAST TWO DAYS | | NUMBER OF OTHER SYMPTOMS EXPERIENCED IN PAST TWO DAYS | |
|---|---|---|---|---|
| | Impaired | Normal | Impaired | Normal |
| 0 | 351 | 408 | 257 | 338 |
| 1 | 84 | 41 | 123 | 79 |
| 2 | 64 | 18 | 85 | 42 |
| 3 | 48 | 15 | 73 | 18 |
| 4 | 37 | 9 | 45 | 12 |
| 5 | 26 | 4 | 28 | 5 |
| 6 | 16 | 6 | 14 | 6 |
| 7 | 8 | 2 | 9 | 2 |
| 8 | 8 | 0 | 4 | 1 |
| 9 | 2 | 0 | 2 | 0 |
| 10 | 0 | 0 | 1 | 0 |
| 11 | 0 | 0 | 1 | 0 |
| 12 | 0 | 0 | 2 | 1 |
| 13 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 |
| Sample Mean | 1.348 | 0.453 | 1.668 | 0.692 |

TABLE 2

BIVARIATE TOBIT SYMPTOM PRODUCTION FUNCTION ESTIMATES: IMPAIRED SUBSAMPLE[a]

| | Chest and Throat Symptoms | Other Symptoms |
|---|---|---|
| CONSTANT | -3.085 | -2.043 |
| | (-3.035) | (-2.125) |
| ASTHMA | 0.8425 | 0.6724 |
| | (2.328) | (1.851) |
| BRONCH | 3.774 | 2.936 |
| | (7.663) | (6.668) |
| SHRTWHZ | 1.494 | 1.235 |
| | (3.683) | (3.428) |
| FLEMCO | 1.458 | 0.2526 |
| | (4.038) | (0.8558) |
| HAYFEV | 1.110 | 0.6613 |
| | (3.509) | (2.365) |
| BURB | -1.431 | -0.7330 |
| | (-2.728) | (-1.539) |
| AGE | 0.2986 | 2.042 |
| | (0.1596) | (1.177) |
| EXPWORK | ---[b] | ---[b] |
| ACCAR | -0.3485 | -0.4395 |
| | (-0.8885) | (-1.364) |
| ACCEN | -1.9961 | -0.6291 |
| | (-2.834) | (-1.829) |
| O3 | -0.1672 | 0.1252 |
| | (-0.5638) | (-.4475) |
| CO | 1.279 | -0.06285 |
| | (1.259) | (-0.06356) |
| NO2 | 0.5475 | 0.6384 |
| | (0.7744) | (0.9282) |
| $\sigma_\nu$ | 2.617 | 2.454 |
| | (17.70) | (20.81) |
| $\sigma_\mu$ | 1.827 | |
| | (21.17) | |
| Chi-Square[c] | 148.7 | |
| P-Value for Wald Test | 0.742 | |
| Number of Iterations[d] | 21 | |

[a]t-statistics are in parentheses.

[b]Denotes omitted dummy variable. Also, long term health status covariates entering these equations do not represent mutually exclusive categories.

[c]The chi-square test statistic is $-2\ln\lambda$, where $\lambda$ is the likelihood ratio, for a test of the null hypothesis that the slope coefficients in both production functions are all zero.

[d]The convergence criterion is 0.5 for the gradient-weighted inverse Hessian.

TABLE 3

BIVARIATE TOBIT SYMPTOM PRODUCTION FUNCTION ESTIMATES: NORMAL SUBSAMPLE[a]

| | Chest and Throat Symptoms | Other Symptoms |
|---|---|---|
| CONSTANT | -5.789<br>(-2.157) | -5.479<br>(-2.790) |
| HAYFEV | 2.316<br>(1.614) | 1.461<br>(1.871) |
| BURB | -1.388<br>(-1.180) | -0.6248<br>(-0.8470) |
| AGE | 4.143<br>(0.7873) | 7.075<br>(2.091) |
| EXPWORK | 0.8707<br>(1.157) | 1.329<br>(2.297) |
| ACCAR | -1.949<br>(-2.905) | -0.6705<br>(-1.057) |
| NOTCASCK | -0.4613<br>(-0.6312) | -0.8565<br>(-1.594) |
| O3 | 0.2757<br>(0.5867) | 0.3592<br>(0.9674) |
| CO | 0.1788<br>(0.07729) | -0.07200<br>(-0.05241) |
| NO2 | 1.841<br>(1.162) | 1.069<br>(1.127) |
| $\sigma_\nu$ | 3.204<br>(10.15) | 2.435<br>(11.31) |
| $\sigma_\mu$ | 1.828<br>(10.44) | |
| Chi-Square[b] | 69.81 | |
| P-Value for Wald Test | 0.610 | |
| Number of Iterations[c] | 20 | |

[a]t-statistics in parentheses.

[b]The chi-square test statistic is $-2\ln\lambda$, where $\lambda$ is the likelihood ratio, for a test of the null hypothesis that the slope coefficients in both production functions are all zero.

[c]The convergence criterion is 0.5 for the gradient-weighted inverse Hessian.

TABLE 4

UNIVARIATE TOBIT SYMPTOM PRODUCTION FUNCTION ESTIMATES[a]

| | Impaired Subsample | Normal Subsample |
|---|---|---|
| CONSTANT | -2.253<br>(-1.263) | -6.085<br>(-2.329) |
| ASTHMA | 1.0333<br>(1.953) | |
| BRONCH | 4.649<br>(7.708) | |
| SHRTWHZ | 1.909<br>(3.242) | |
| FLEMCO | 1.769<br>(3.607) | |
| HAYFEV | 1.574<br>(3.137) | 2.216<br>(2.378) |
| BURB | -1.830<br>(-2.927) | -1.623<br>(-1.126) |
| AGE | 1.200<br>(0.4034) | 6.351<br>(1.165) |
| EXPWORK | ---[b] | 1.725<br>(2.039) |
| ACCAR | -0.5900<br>(-2.585) | -1.260<br>(-2.425) |
| O3 | 0.1629<br>(0.4846) | 0.5941<br>(1.616) |
| CO | 1.013<br>(0.8041) | 0.3722<br>(0.2163) |
| NO2 | 0.8930<br>(1.130) | 1.726<br>(1.784) |
| $\sigma_\nu$ | 3.884<br>(37.29) | 3.790<br>(22.47) |
| $\sigma_\mu$ | 2.582<br>(15.84) | 2.516<br>(8.822) |
| Chi-Square[c] | 77.88 | 36.45 |
| P-Value for Parameter Restrictions | 0.623 | 0.562 |
| Number of Iterations[d] | 8 | 5 |

[a]t-statistics in parentheses.

[b]Denotes omitted dummy variable. Also, long term health status covariates entering these equations do not represent mutually exclusive categories.

[c]The chi-square test statistic is $-2\ln\lambda$, where $\lambda$ is the likelihood ratio, for a test of the null hypothesis that the slope coefficients in both production functions are all zero.

[d]The convergence criterion is 0.5 for the gradient-weighted inverse Hessian.

TABLE 5

MARGINAL WILLINGNESS TO PAY TO RELIEVE SYMPTOMS AND AVOID AIR POLLUTION

| | IMPAIRED SUBSAMPLE | | | |
|---|---|---|---|---|
| | Symptoms | O3 | NO2 | CO |
| Mean | $1.12 | ---[a] | ---[a] | ---[a] |
| Median | $1.09 | | | |
| Maximum | $1.90 | | | |
| Minimum | $0.81 | | | |

| | NORMAL SUBSAMPLE | | | |
|---|---|---|---|---|
| | Symptoms | O3 | NO2 | CO |
| Mean | $0.73 | $0.31b | $0.91b | ---[a] |
| Median | $0.70 | | | |
| Maximum | $1.22 | | | |
| Minimum | $0.49 | | | |

[a]Denotes coefficient not significantly different from zero at 10 percent level using one tail test in estimated equations presented in Table 4.

[b]Estimates of willingness to pay for reduced air pollution do not vary across sample members. In the computational ratio, respondent specific information appears both in the numerator and denominator and therefore cancels out.

# VALUATION OF MORBIDITY REDUCTION DUE TO AIR POLLUTION ABATEMENT DIRECT AND INDIRECT MEASUREMENTS

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ABSTRACT

The paper is a comparative study of alternative approaches to the valuation of a public good - air quality, in terms of its effect on morbidity levels. Three indirect approaches have been employed in the study: (1) cost of illness, (2) household health production, and (3) a market goods approach, involving the derivation of willingness to pay for clean air by exploiting the relationships among the public and market goods. The direct valuation approach encompassed several contingent valuation experiments: (1) open-ended, (2) probe biding, and (3) binary choice. The estimates of welfare change valuations derived under the various approaches are discussed and compared. The empirical analysis is based on results from a household survey, consisting of a stratified random sample of about 3,300 households from the Haifa metropolitan area (in northern Israel). It was carried. out over a period of 12 months during 1986-87.

VALUATION OF MORBIDITY REDUCTION DUE TO AIR POLLUTION ABATEMENT
DIRECT AND INDIRECT MEASUREMENTS*

## 1. INTRODUCTION

The attributes of environmental quality, a public good, require the adoption of different valuation approaches than those customarily employed in studies of market goods. Basically, our aim is to quantify the change in consumer welfare, or benefits, measured in money units, associated with a change (an increase or a reduction) in the quantity of the environmental good (and the flow of services concurrent with this change). Willingness to pay (WTP) is the term commonly used to denote this welfare change. The monetary measures of welfare change are the compensating variation and equivalent variation, or surplus in the case of nonmarket goods where quantity, rather than price changes are involved. The compensating surplus (CS) is defined as the income change which offsets the change in utility induced by a change in the level of the public good, y,holding utility constant at its original level. In terms of the expenditure function, $\mu$, it is given by:

$$CV = \mu(y^0;\ P_X^0,\ V^0) - \mu(y^1;\ P_X^0,\ V^0), \qquad (y^1 > y^0) \qquad (1)$$

where the superscripts indicate initial (0), or subsequent (1), states, $P_X$ is the vector of market goods prices, V is the indirect utility function, $V(P_X, M, y)$, M is the expenditure on the market goods, and y is the public good. Analogously, the equivalent

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surplus (ES) is the change in income equivalent to the utility gain induced by a change in the level of the nonmarket good, holding utility at its subsequent level:

$$EV = \mu(y^0;P^0_X, V^1) - \mu(y^1;P^0_X, V^1) \qquad (2)$$

Two totally different approaches for the valuation of air quality have been used. The first employs *indirect* methods, all of which essentially attempt to infer the implicit value of the public good from observable (and presumably accurately measured) prices of private goods and services. For example, air quality affects housing prices as well as expenditures on preventive and medical care that are associated with the effect of pollution on health. Changes in air quality levels would be expected to shift the observed demand schedules for these market goods. From the extent and direction of these shifts, implicit prices (or marginal willingness to pay valuations) of the relevant public good might be inferred. The use of market data in the valuation of environmental goods has been expounded by Mäler (1974), Freeman (1979], and more recently and exhaustively by Bockstael, et al. (1984), and Johansson (1987). One of the indirect approaches used in this study has to the best of our knowledge seldom been used in the valuation of public goods in general, and environmental goods in particular, and in this sense constitutes a novel contribution.

"Traditional" indirect approaches employed in valuing environmental resources involved techniques such as the travel cost method (TCM), characteristically used in recreation demand studies, or the hedonic price method (HPM), which has been used to monetize urban public amenities through the analysis of housing markets (e.g., Brookshire, et al., 1982, who studied air pollution effects on property values in California). In TCM, for example, researchers have attempted to value the benefits of a public good, e.g. water quality, associated with the provision of outdoor recreation services (the latter being, at least in principle, a market good).

Household health production is another indirect method. It focuses on the consequences of health damages associated with an inadequate supply of an environmental good, such as clean air and water (e.g., Cropper, 1981, Gerking and Stanley, 1986, Berger, et al, 1987). Here one posits technical relationships between the individual consumer’s health attributes, exposure to environmental pollution, and the consumption of private goods that affect health (such as medical services, or goods which help protect against exposure to health risks). The maximization of utility derived from the consumption of goods and services and from being healthy, given these relationships, yields an implicit value assigned by the consumer to the environmental good under study.

Closely related to the health production approach, is the “cost-of-illness” (COI) method, long used by economists and medical researchers to value the damages inflicted by environmental pollution, and hence the value attributable to Improvements in the supply of environmental goods. Here one estimates the expenditure on medical services and the value of lost work and productivity associated with excess morbidity or mortality. Although easiest to apply in terms of data availability, it can be shown Harrington and Portney, 1987) that this method yields an underestimate of the (theoretically correct) value of the public good.

Alternatively, an altogether different approach, less and less hesitantly used economists, especially in the valuation of environmental and amenity resources, is a *direct* approach, in the sense that it attempts to elicit consumers’ valuations through survey interview methods. This is the contingent valuation method (CVM) - which elicits valuations within a framework of a hypothetical, contingent market for the good or service in question. The “state-of-the-art” of the contingent valuation method has been summarized by Cummings, et al ( 1986) and, more recently, by Mitchell and Carson (1989).

The different approaches investigated in the present study are described in Figure 1 (the residential property hedonic model is not dealt with here, however). In this paper we apply them to the valuation of benefits derived from reducing air pollution-induced morbidity.[1] To the best of our knowledge, ours is the first comprehensive study which has employed most of the approaches currently used by economists to derive monetary values of pollution-induced health damages, based on a single, large primary micro-data base.

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Figure 1

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The data were collected through a household survey, carried out the author in the city of Haifa in northern Israel, over a 12 month period in 1986-87. All the approaches employed in the study (with the exception of the residential prices hedonic model) are based on the same set of sample observations. This made it possible to carry out a rather comprehensive empirical analysis of the different approaches.

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Section 2 of the paper describes the study area, the survey design and the data collected, as well as presenting a number of selected epidemiological results. Section 3 deals with the CVM experimental design and valuations. Section 4 details the specific indirect market goods model employed in this study. In section 5 we present a brief description of the household health production mode 1, and in Section 6 the results from the COI analyses, focusing on the estimation of due to production gains from reducing work losses. A comparative analysis in Section 7 sums up

[1] A survey of economic studies which have dealt with the valuation of morbidity damages associated with environmental pollution has just recently been published. See Cropper and Freeman (1988). Berger, et al. (1987) have compared CVM with COI using a small sample of Chicago and Denver residents.

the alternative valuation approaches.

## 2. DATA AND STUDY DESIGN

### 2.1 Background

Haifa, is an industrial city in northern Israel, situated on the slopes of Mt. Carmel and the adjoining Haifa Bay area. The combination of the region's topography and meteorological conditions, and a concentration of heavy industry in the lower Bay area (a power plant, oil refineries, a petrochemical complex, and others) create conditions conducive to high ambient concentrations of pollutants, especially $SO_2$ and particulate, in parts of the metropolitan region (depending on topography and wind direction) during certain periods of the year.

Maximal mean 24-hour $SO_2$ concentrations of 197 and 286 $\mu g/M^3$ were recorded in 1986 and 1987, respectively, with corresponding maximal half-hour readings of 1,271 and 2,552.[2] During the period January 1986 - April 1987, 15 violations of the absolute $SO_2$ standard were recorded in Haifa. An Intermittent Control System (ICS) which directs the area's major polluters to switch to low-sulfur fuels during environmental episodes, was activated on 23 days. In one single day, April 12, 1996, the monitoring stations registered 12 violations of the 99% standard and 2 of the 100% standard. It had been estimated that on that day alone the ICS had prevented the occurrence of at least 6 additional violation of the absolute standard! (Environmental Protection Service, 1988). It has also been noted that during the same period measurements of sulfates concentrations at certain neighborhoods (these are not taken on a regular basis) have registered a

[2] Currently there are two ambient standards for $SO_2$: A 99% "statistical" standard of 780 $\mu g/M^3$ (300 ppb), with a 1% exceedance level (176 half-hours per year), and an absolute standard of 1560 $\mu g/M^3$ (600 ppb). An expert committee has recently proposed converting the 99% standard into a single, 100% standard.

three-fold increase over those measured in 1976. High values of CO were also recorded in some areas of the city during the report period.

Concomitantly, evidence has been accumulating indicating a higher incidence and prevalence of respiratory illnesses in the area. Expansion, actual or planned, of the power and petrochemical industries has fostered the familiar Conflict between economic development, regional employment and income, on one hand, and the desire for a cleaner environment, on the other hand. This, as expected, has stimulated a good deal of public controversy and media involvement.

## 2.2 The Household Survey

A household survey, based on a stratified, cluster area probability sample of about 3,600 households, in the metropolitan area of Haifa was carried out from May 1986 through April 1987. The sample was drawn from 137 Census Statistical Areas (CSA), classified into four socioeconomic groups on the basis of the latest (1983) Census. They were then further classified into three levels of ambient pollution. 16 CSAs, each approximating a different residential neighborhood, were selected to represent the 12 sampling strata. City blocks were randomly sampled within each stratum. Heads (either spouse) of all the households within each block were interviewed. The data were collected in the course of a structured interview, lasting about 30-45 minutes. The overall response rate was 81%; 9% refused to be interviewed, and another 10% could not be reached after a second visit.

Beside the usual socioeconomic and demographic data, and CVM questions (discussed below), respondents were asked about perceived air pollution levels in the neighborhood and the work place, and attitudes towards air pollution. The questionnaire included questions on self-assessed health status, present and past smoking habits of household members, and respiratory system-related symptoms and diseases of the respondent and household members. These included the following: Cough and phlegm; coughing or phlegm production first thing in the morning in summer ant/or winter, and at other times of the day; and wheezing and its relationship to having a cold. Additional symptoms and diagnoses were elucidated, in relation to the respondent or other household members: Eye “infection”, sinusitis, allergic irritation of nose or eyes, eczema, headache, a running nose, dyspnoea (with or without effort), pneumonia, bronchitis, and asthma (including frequency of attacks over the preceding 12-month period for the latter three). Use of medical services (primary clinic visits, medications), bed days during a two-week recall period, and hospitalization during the 12 months preceding the interview by any member of the household were also recorded.

## 2.3 Some Epidemiological Findings

A dichotomous logit model served to characterize respiratory system diseases and symptoms by fitting the model to a binary (0-1) dependent variable, where 1 indicates a reported presence, and 0 the absence of a given symptom or disease. The logit model fits the data to an equation where the dependent variable is specified as the natural logarithm of the odds, $y = \ln p/(1-p)$, p being the probability of observing the phenomenon (symptom or disease) and 1-p the probability of not observing it, and y is regressed against a set of explanatory variables. Separate equations were estimated for respondent, his or her spouse, and the family’s children (the latter grouped as one observation). Thus, the fitted equation is of the form:

$$y = \ln p/(1-p) = a + b\mathrm{xPOL} + \Sigma c_i X_i. \qquad (3)$$

where POL is the variable indicating pollution level (perceived by the respondent, or measured) In the relevant neighborhood, and the $X_i$’s are other explanatory variables. For a dichotomous classification of neighborhood pollution (used in this analysis), an odds ratio, indicating the relative “riskiness” of a polluted neighborhood with respect to the prevalence of a given symptom or disease, is denoted by *p,* whose pint estimate is given by

$$y(1) - y(0) = b = \ln \rho = \ln \left[ (p/1-p)\big|_{POL=1} \;/\; (p/1-p)\big|_{POL=0} \right]$$

$$\therefore \rho = e^{b} \qquad (4)$$

Thus it has been assumed that there is a constant ratio between the two odds ratios for given values of the other relevant variables, and that this ratio is independent of those variables when individuals with similar attributes, but residing in different neighborhoods, are compared.

Table 1 and Figure 2 give the odd ratios (in Table 1 also the upper and lower confidence intervals) for various symptoms and diseases. It should be stressed that there relationships are also controlled for smoking habits (which tend to cause similar symptoms). Only findings in which the lower 95% confidence interval is more than 1 are reported. There is a marked consistency of the findings and the significant relationship between exposure to air pollution and various measures of morbidity is clear. The analysis of data relating to the spouse of the respondent revealed similar findings. The findings in relation to the children in the households also reveal a relationship between morbidity measures and exposure to air pollution (where the smoking habits controlled for are those of the parents).

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**Table 1**

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**Figure 2**

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3. DIRECT VALUATIONS: CVM

3.1 Elicitation Technique and Analysis of Responses

Economists have long since shown that the correct measure of welfare changes due to pollution reduction, and the associated health improvements, should be based on people's willingness to pay (WTP) for pollution abatement (Schelling, 1968; Mishan, 1971). Conceptually, this measure should capture the four components which constitute morbidity damages, namely, (a) opportunity cost of time sick, (b) out-of-pocket and indirect (public) outlays for medical services, (c) defensive expenditure, and (d) psychological losses associated with suffering, pain, hedonic damages, and other direct utility losses not accounted by the first three categories. A comprehensive approach to pollution-induced health damage valuation should incorporate all four components. The money equivalent of these damages is represented by WTP for enhancing ambient air quality, through the implied reduction in exposure to morbidity risks. Of course, other benefits associated with air pollution abatement should be excluded in this case.

In the present study, pre-testing has shown that - at least in the case of Israeli respondents - questions which attempted to elicit monetary valuations for reduced morbidity (e.g., reduction in a stated number of bed days, the number of days with respiratory symptoms, or the number of acute situations during a given period), were ill received by the respondents, or they had difficulties relating to the situations described in such questions. Hence, it was imperative to state WTP in terms of reduction in pollution levels. The Israeli public in general, and in Haifa in particular, is well aware of the connection between air pollution and respiratory ailments, although of course not necessarily of the true dose-response relationships.

Interviewees were queried about the perceived air pollution levels in their own neighborhood. In order to provide a visual stimulus, they were shown photographs of the city of Haifa on visibly polluted and on relatively clean days.[3] They were asked to state their maximum willingness to pay for pollution abatement: (a) In order to prevent a 50% reduction of present air quality level of their neighborhood; (b) To achieve a 50% Improvement in

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[3] The pollution levels shown in the pictures did not necessarily correspond to the indicated changes in pollution levels, and mainly served to introduce a measure of realism to the hypothetical nature of the CVM environment.

present neighborhood levels.[4] The first measure corresponds to ES (and following Randall and Stoll, 1980, will be denoted by $WTP^e$); the second corresponds to CS (denoted by $WTP^c$). The notation serves to emphasize that both are willingness to pay measures, not willingness to accept (WTA) ones. Because of the inherent difficulties in obtaining non-inflated WTA responses it was we decided against employing them in the questionnaire, given the possibility that this could have mired the WTP responses as well.[5]

The payment vehicle was the municipal property tax, which is the sole local tax. Respondents were asked to state their WTP in terms of a percentage of the annual tax assessment (over and above their present tax assessment), by selecting the appropriate percentage figure from a payment card[6]. Respondents who were not willing to pay any sum were asked about the reasons for the zero valuation. It was thus possible to distinguish between “true” 0’s, i.e. people who did not place any positive value on the improvement (or, alternatively, the prevention of deterioration), and those who Implicitly registered a protest vote for a variety of reasons (objecting to the payment vehicle, believing that the polluter should pay, and so on), but who did not necessarily view

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4 Specifically, they were instructed to refer back to the perceived level which they had previously indicated as the one prevailing in their area.

5 On the use of WTA vs. WTP in CVM, and the controversies surrounding their derivation in empirical studies,see Bishop and Heberlein (1979); Knetsch and Sinden (1984); Gregory (1986); Mitchell and Carson (1989).

6 Percentage categories (from 0% to 100%) were listed on the card in either ascending or descending order, vertically or horizontally These options were randomly assigned to households. The upper 100% limit did not seem to constrain the range of WTP responses. While 90% of the $WTP^e$ or $WTP^c$ values were below 100 NIS, only 0.4% of the households were in the 100 NIS or less tax bracket.

air quality improvement as valueless[7].

The variables found to be significant in explaining the variation in $WTP^c$ and $WTP^e$ (exclusive of protest zero bids) are presented in Table 2. Since the analyses of the CVM experiments focused on the subset of positive bidders, it was necessary to correct for a possible selection bias introduced by dropping the zero responses. A procedure accounting for this bias is described in Maddala (1983).[8] The analysis proceeded in two steps. First, a probit model is used to analyze the determinants of zero bids, where the dependent variable takes a value of 1 if WTP>0, and 0 otherwise. In the second step positive responses are analyzed separately, with the probit model providing an estimator to correct for the selectivity effects resulting from dropping the observations with zero bids. The adjustment factor is given by the ratio $\phi(V)/\Phi(V)$, where $\phi$ and $\Phi$ are the normal probability density function and cumulative density function, respectively, and $V=b'\underline{x}$. The b's are maximum likelihood estimators from the probit analysis, end $\underline{x}$ is a vector of explanatory variables belonging to three categories: variables associated with the respondent's - or other family members' - health status, demographic and socioeconomic variables (age, sex, education, birth origin, work status, family size), and attitude shaping variables, such as perception of the authorities' involvement with pollution control, the amount of annual taxes paid, and perceived exposure to air

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[7] Our interpretation of the data is that although some vehicle bias exists, it has had only a limited impact upon the results. Out of about 35% of respondents whose WTP=0, 21% (for $WTP^c$) and 17% (for $WTP^e$) gave reasons which could possibly imply an objection to the payment vehicle itself ("I already pay too much tax"; "I am not willing to pay any more taxes"). Namely, altogether approximately not more than 7% of all respondents were affected by the vehicle to such an extent that they refused to pay any positive sum. Of course, the sums offered by other respondents may have also been affected to some unknown degree.

[8] It was applied by Kealy and Bishop (1986) in studying recreation use behavior, and by Smith and Desvousges (1987) in a CVM study on risks of exposure to hazardous wastes.

pollution at home or at the work place. There has been an expected marked improvement in $R^2$ when the equations were estimated over the set of nonzero bid observations.

**Table 2**

The estimated regressions of nonzero $WTP^c$ and $WTP^e$ bids, for the subset of standard WTP responses (see the section below) are reported in table 2 (n=2,230). Respondents who are younger, female, and from a higher socioeconomic status tend to be willing to pay more to improve air quality, or prevent its further deterioration. Respondents who are more aware of pollution in their neighborhoods or work place, who believe too little is spent on pollution control, believe government Is not too effective in controlling it, and are willing to devote of their time in public activities to this end, are also willing to contribute more towards this goal. And those who themselves, or their families, suffer from the ill health effects of pollution, are also willing to pay more to control it.

3.2 Contingent valuation experiments

The sampling design used in the study afforded the possibility of experimenting with alternative CVM formats, used for difference subsets of the sample, each of which could be viewed as a separate random sample from the same population. The only difference between these samples was that they were taken at different points in time. Clearly, to the extent that time of year affected the CVM responses, the statement above would have to be qualified.

The first set of questionnaires ($n \cong 2,300$), the “standard” CVM format was used, namely, an open-ended WTP question. The respondent was asked to state his or her maximum WTP for the proposed change.

It has been suggested that a more "natural" way to conduct CVM surveys, thereby adding realism and reducing the inherent hypothetical element, is through the use of a "Buy - Not buy" choice implied by the binary choice format (Cummings, et al, 1986). To this end, a second set of questionnaires ($n \cong 450$) replaced the standard format with a binary choice format, in which respondents were asked to state whether they would be willing to pay a given percentage increase in the municipal tax for the same ±50% changes in pollution levels. The percentage categories were drawn from the pay card table, and randomly assigned to households.

To analyze these responses, behavior is usually modeled in a stochastic fashion, often by positing a random utility model to represent consumer behavior. While the binary choice format does not provide the investigator with information regarding the sample distribution of WTP valuations, it does nevertheless enable to deduce its first moments - the mean and the median. These can be compared with the corresponding statistics of the distributions obtained from the other experiments. Our analysis followed the work of Hanemann (1984) and Loehman and De (1982).

A third variant of the CVM format ($n \cong 490$) was aimed at attempting to elicit respondents' true *maximum* WTP statements, by asking them whether they would have agreed to Increase - and then by how much - their initial sums had they been informed that that sum would not be sufficient to accomplish the indicated 50% change.

In the course of the survey doubts were raised whether respondents were indeed interpreting it to be a one-time payment, instead of an annual contribution, in conjunction with the payment of their annual municipal taxes. To this end, a fourth change, involving a different subset of about 400 respondents, modified the nature of the payment, from a one-time to an *annual* payment.

Tables 3 and 4 display various statistics for the four experiments, and for the overall sample: “Standard” maximum WTP, repeat bidding, binary choice, and annual vs. one-payment, for $WTP^c$ and $WTP^e$ valuations, respectively. responses. We present here the results for the analyses excluding “protest” zero-bidders (identified through the follow-up question).

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Table 3

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Table 4

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In general, $WTP^e > WTP^c$, namely, on average respondents were willing to pay more to prevent worsening of pollution than to improve present levels. However, as noted above, unless we know the shape of the indifference curves we cannot say a priori whether this indeed should be the case.

Means of the binary choice format are surprisingly close to those of the standard, and especially the repeat-bid, formats. Though eliciting less information (WTP above or below a certain value, but not actual WTP itself), the resulting welfare change estimates do not very much from the standard format (particularly $WTP^e$ valuations), or from both $WTP^c$ and $WTP^e$ in the repeat bid valuations. The results suggest that, given the simplicity of the binary choice format, it should be considered first as the preferred alternative, particularly where there would not be any special interest in obtaining the sample distribution of the CVM valuations.

Regarding the repeat bidding elicitation procedure, we found a significant increase in mean $WTP^c$ and $WTP^e$, for those respondents who were willing to increase their payments (who make up only a subset of all respondents, as one would expect), and who gave a consistent answer. We tend to interpret these results as evidence of the efficacy of this approach in deriving better WTP estimates, supporting Mitchell and Carson’s (1986) advocacy of it.

We did not find significant differences between the responses of the annual and one-payment groups, supporting our suspicion that respondents processed the WTP questions in the same way they would relate to the annual municipal tax payment.

### 3.3 $WTP^c$ vs. $WTP^e$ responses

A different analysis of WTP responses is presented in Table 5, where a different grouping of mean sample values of WTP and WTP for air quality changes is presented. The table is based on responses from the subset of standard WTP questionnaires. Neighborhoods (=CSA's) were divided into the three pollution levels. With regard to $WTP^c$, it was assumed that a 50% improvement roughly implies that a neighborhood with moderate air quality would be upgraded into one with good air quality, i.e., a (relatively) clean one, and that a "bad" neighborhood would move into the "moderate" category. Similarly, with respect to $WTP^e$, a 50% deterioration In pollution levels would imply a downgrading of a relatively clean neighborhood to one with moderate levels, and so on.[9] Thus, on average, an individual living in a moderately polluted neighborhood (according to his or her perception) would be willing to contribute NIS 37.9 annually towards improving air quality, and NIS 40.0 In order to prevent a worsening of present levels.

Table 5

The relationship between these two welfare change measures for any given sub-sample of neighborhood households is ambiguous. While $WTP^e > WTP^c$ for moderately polluted neighborhoods, the reverse holds for those badly polluted. However, both $WTP^c$ and $WTP^e$ increase with pollution levels, and the between-group

[9] The neighborhood marked "Very poor" in Table 5 is a fictitious neighborhood, created by hypothetically downgrading the "poor" neighborhood category.

differences are significant (non-parametric median test). The two-sample mean tests indicate that although $WTP^c$ and $WTP^e$ differ significantly, $WTP^c > WTP^e$ in one case (respondents from poor-quality neighborhoods), but the reverse holds for moderate-quality neighborhoods.

### 3.4 Reliability of CVM valuations

Doubts about the truthful revelation of preferences obtained through direct questioning procedures still dominate many discussions involving the use of direct WTP valuations. Four "Reference Operating Conditions" (ROC's) have been proposed by Cummings, et al (1986), as criteria for evaluating CVM applications in general, and for evaluating the accuracy of the values obtained in particular. These conditions are (a) familiarity with the commodity, (b) prior valuation and choice experience with respect to consumption levels of the commodity, (c) the presence of little uncertainty and, (d) the use of WTP, rather than WTA (willingness to accept) valuations.

In examining these conditions In the context of the present study, we note first that the city of Haifa and its environs provide a suitable setting for obtaining WTP responses in a CVM environment. Its topographical layout and the location of its industry introduce inter-neighborhood variability in ambient air quality, about which there is a fair level of public awareness. In recent years, the local media have frequently addressed the issue of air pollution-induced diseases. It is therefore likely that respondents were not placed in a position of having to respond to hypothetical CVM questions. Moreover, it has been surmised that a willingness to pay for air pollution abatement would tend to involve little or no strategic biases attributed to CVM surveys, because relatively small sums of money (per household) are typically involved. Thus, of the four conditions noted above, the first and the last have been satisfied in this study. [10]

Regarding ROC #2, all that can be claimed is that subjects were familiar with the vehicle (city property tax assessments), although, naturally, they had had no prior experience with valuing air quality in this particular manner. However, it is doubtful whether ROC #3 was fulfilled in this study. First, uncertainty is ingrained in dose-response relationships between air pollution and health, especially when lay people are involved. Secondly, an altogether different type of uncertainty may have surrounded the stipulated change in the supply of the "paid-for" commodity (the indicated level of air quality improvement), had the payment indeed been made. Although the phrasing of the relevant question attempted to alleviate this source of uncertainty, we have no way of ascertaining whether this had been successfully achieved.

### 3.5 Population CVM Estimates

Population estimates of $WTP^c$ and $WTP^e$ for the entire Haifa metropolitan region, were derived using the following entities:

$N_{is}$ = The number of households in the i-th CSA by employment status (s) of the head of the household (employed, self-employed, and unemployed].

$I_s$ = Average net monthly income per household of households whose heads were employed (Central Bureau of Statistics, 1985b). Since income of self-employed by CSA is not available, it was determined on the basis of sample means, after proper adjustments. Income levels were converted to 1987 NIS using the Cost-of-Living Index and the change in real income of salaried workers (Bank of Israel, 1988).

All census areas were classified by socioeconomic level (e)

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[10] Indeed, the survey indicates that subjects were highly familiar with the various pollution levels in their respective neighborhoods. As noted in an earlier footnote, a high partial correlation between measured and perceived pollution levels is evident.

and pollution level (p), corresponding to those used in delineating the sampling strata. Using these data, $WTP^c$ and $WTP^e$ totals for each CSA, were derived by grouping all CSA's (sample and non-sample) according to their respective socioeconomic level (e) and pollution level (p). Each CSA was further sub-divided by employment status. The corresponding sample CSA mean WTP value was used for calculating population totals for each sub-group within each CSA. Regional totals were then obtained by aggregating employment-group totals within each CSA, and then aggregating over all CSA's. Total regional annual benefits of pollution reduction ($\Sigma WTP^c$) and of prevention ($\Sigma WTP^e$) amounted to NIS 3.9 and 9.9 mil., respectively (at the then prevailing exchange rate of 1.5 NIS to $ 1 US, $2.6 and 6.6 mil.)

## 4. INDIRECT VALUATION: DERIVING EXACT WELFARE CHANGE MEASURES

### 4.1 Introduction

In calculating benefits associated with a larger supply of the environmental public good through its relationship" with some market good(s), one might begin with estimating a demand function for the market good from observed price-quantity data. The benefits from the public good would be derived by computing the change in consumers' surplus associated with a corresponding shift in the *market* demand schedule. This method would be expected to yield an *approximate* value of the potential welfare change (Just, et al, 1982). Alternatively, *exact* (in the theoretical, not statistical, sense) measures of welfare change may be obtained by evaluating an expenditure function underlying the ordinary market-good demand system, using duality theory (Hausman, 1981; Vartia, 1983; Loehman, 1986). This approach is discussed in this section.

In order to eventually "untangle" the demand valuations of the public good from those observed for the market goods, the posited demand system ought to satisfy two conditions. The market and nonmarket goods must be non-separable, and a price vector which would drive the marginal utility from the nonmarket goods to zero should exist (Mäler, 1974). These conditions enable the recovery of the preference ordering for this group of goods and, subsequently, the compensated demand (or marginal willingness to pay) schedule for the public good, from which valuations of changes in the quantity of that good can be derived. The demand system specified below satisfies the first condition; the second condition is not testable, but assumed.

Specifically, in this study a twice differentiable indirect utility function was assumed. Duality theory (Roy's identity) is invoked in deriving the corresponding budget share equations. This partial system[11] encompasses two market goods, housing services and medical services, denoted by the vector X in the formulation below," and a public good, air quality, denoted by y. The expenditure function, derived from the posited indirect utility function, is then used to calculate the monetary value of welfare changes associated with shifts in the level of air quality. By Shephard's Lemma, the partial derivative of the expenditure function with respect to price yields a Hicksian compensated demand function (cf. Varian, 1984); the derivative with respect to the public good yields the demand "price" function for the public good.

We know of only one recent study which adopted a similar, indirect market good approach to the empirical estimation of the

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[11] Partial demand system are frequently encountered in empirical studies. This is characteristically due to data limitations which preclude the estimation of all the unknown parameters in the complete demand system. In order to recover the preferences for the nonmarket good from the *partial* system it is necessary to assume that the group of commodities which make up the partial system is separable in consumption from all other commodities (Hanemann and Morey, 1987). These authors go on to show that the compensating and equivalent measures calculated from a partial demand system need not be identical with those calculated from a full system. CV would be a lower bound on the conventional compensating measure, while EV might be greater than, less than, or equal to the full system measure.

benefits associated with an environmental good (Shapiro and Smith, 1981). Our paper differs in its use of individual, micro data, as compared to their use of aggregate data, and in deriving exact welfare measures (which was not the focus of that paper). In connection with measuring cost of living changes, Cobb (1987) has used a "translating variables" specification in incorporating nonmarket goods in budget share equation systems.

4.2 Model specification and estimation

The specification chosen for the indirect utility function is the translog function (Christensen et.al., 1975), defined in terms of normalized prices of the two market goods, $P^{*}=P_i/M$, the nonmarket good - air quality - y, and household characteristics:

$$\begin{aligned} \ln V = {} & \alpha_0 + (1 + \ln y) + (\alpha_1 + \gamma_1 \ln y) \ln P_1^{*} + (\alpha_2 + \gamma_2 \ln y) \ln P_2^{*} + \\ & + \frac{1}{2}\Big[(\beta_{11} + \delta_{11} \ln y)[\ln P_1^{*}]^2 + (\beta_{12} + \delta_{12} \ln y)\ln P_1^{*} \ln P_2^{*} \\ & + (\beta_{21} + \delta_{21} \ln y)\ln P_1^{*} \ln P_2^{*} + (\beta_{22} + \delta_{22} \ln y)[\ln P_2^{*}]^2\Big] \\ & + \ln P_1^{*} [\phi_{11}h_1 + \phi_{12}h_2 + \phi_{13}h_3 + \phi_{14}h_4 + \phi_{15}h_5] \\ & + \ln P_2^{*} [\phi_{21}h_1 + \phi_{22}h_2 + \phi_{23}h_3 + \phi_{24}h_4 + \phi_{25}h_5] + \Sigma \phi_i h_i \end{aligned} \tag{5}$$

where $P_1^{*}$ is the (normalized) price of housing services, and $P_2^{*}$ is the (normalized) price of medical services. The $h_i$'s are dichotomous variables which represent family or head of household health characteristics: $h_1$ - smoking habits, $h_2$ - respiratory illness symptoms (head of household), $h_3$ - respiratory illness symptoms (all other household members), $h_4$ - respiratory diseases (head of household), and $h_5$ - respiratory diseases (all other household members).

By Applying Roy's identity to eq. (5) the following share equations are derived:

$$-\frac{\partial \ln V}{\partial \ln P_i} \Big/ \frac{\partial \ln V}{\partial \ln M} = S_i = \frac{PX_i}{M} =$$

$$= \left\{(\alpha_i+\gamma_i \ln y) + (\beta_{ii}+\delta_{ii}\ln y)\ln P_i^* + \tfrac{1}{2}(\beta_{ij}+\delta_{ij}\ln y)\ln P_j^* + \tfrac{1}{2}(\beta_{ji}+\delta_{ji}\ln y)\ln P_j^* + \sum_{k=1}^{5} \phi_{ik}h_k \right\} \Big/ D \qquad i=1,2 \qquad (6)$$

where

$$D = (\alpha_i+\gamma_i\ln y)+(\alpha_j+\gamma_j\ln y) + (\beta_{ii}+\delta_{ii}\ln y)\ln P_i^* + (\beta_{jj}+\delta_{jj}\ln y)\ln P_j^* + \tfrac{1}{2}(\beta_{ij}+\delta_{ij}\ln y)(\ln P_i^* + \ln P_j^*)+\tfrac{1}{2}(\beta_{ji}+\delta_{ji}\ln y)(\ln P_i^* + \ln P_j^*).$$

$S_i$ is the share of the ith market good in total expenditures, M. Symmetry constraints (analogous to the integrability condition from demand theory, see Christensen, et al., 1975) have been imposed on the demand system, viz., $\beta_{ij}=\beta_{ji}$, $\delta_{ij}=\delta_{ji}$ and $\phi_{1k}=-\phi_{2k}$ for all k, causing the characteristic variables to drop out of D above (*cf.* Jorgenson and Slesnick, 1987).[12] Furthermore, the budget share equations should be homogeneous of degree zero in the parameters. To this end, a convenient. normalization which guarantees this condition is $\sum_i \alpha_i=-1$ (cf. Christensen and Manser, 1977). The demand system should also satisfy the adding-up restriction, $\sum_i S_i=1$, which implies that the parameters of the second equation in our two-equation system, can be determined from

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12 Note that after some rewriting, equation (6) takes the following form:

$$S_1 = \{\ldots+ [\tfrac{1}{2}(\beta_{12}+\beta_{21}) + \tfrac{1}{2}(\delta_{12}+\delta_{21})\ln y]\ln P_2^* + \ldots\}/D$$

$$= \{\ldots+ (\beta_{12}^*+\delta_{12}^*\ln y)\ln P_2^* + \ldots\}/D$$

$$S_2 = \{\ldots+ (\beta_{21}^*+\delta_{21}^*\ln y)\ln P_1^* + \ldots\}/D$$

where $\beta_{12}^*=1/2(\beta_{12}+\beta_{21})$, etc. Since the parameters $\beta_{12}$, $\beta_{21}$, $\delta_{12}$, and $\delta_{21}$ are not identifiable when estimating the share equations, the parameters $\beta_{12}^*=\beta_{21}^*$ and $\delta_{12}^*=\delta_{21}^*$ are estimated instead. To simplify notation, however, the asterisks have been *suppressed* in the rest of the paper.

those of the first system; hence, only one equation needs to be estimated. We may note that the present data base has made it possible to incorporate individual health characteristics, related to respiratory illnesses and symptoms, into the posited preference function.[13] In this sense, the present indirect valuation can also be likened to the household health production approach used to evaluate morbidity and mortality benefits (see below).

Annual municipal tax assessments were used as proxies for housing prices in the estimation of the budget share (eq. 6). Its rates generally reflect dwelling quality and the socioeconomic status of the neighborhood. This variable was used instead of imputed rental value because there are no reliable, published statistics on housing prices by neighborhood and housing quality. Consumption of housing services has been assumed to be given by dwelling size.

The price of medical services was calculated as a weighted index of national, average estimates of primary clinic cost per patient visit and hospitalization costs for all illnesses. Consumption of medical visits was given by a predicted number of clinic visits, derived from a logit regression analysis of the survey data.[14] Hospitalization data were taken directly from the

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[13] For the inclusion of characteristics in an indirect translog utility function, see Woodbury (1983), in connection with a model describing labor compensation. The characteristics there are parameters which describe the worker or the work place. In a similar vain, Morey (1985) incorporated personal and site attributes in estimating a demand system for ski resorts (see also Jorgenson and Slesnick, 1987).

[14] Respondents were asked whether they visited a clinic during a two week recall period prior to the date of the interview. The logit regressions yielded predicted probabilities of at least one visit during the two week period as a function of socioeconomic and health characteristics, and a seasonal variable. These probabilities were then converted into an expected annual number of visits for each household.

questionnaire, where respondents were asked to indicate whether they had been hospitalized for respiratory system-related illnesses during the 12-month period preceding the interview.[15] The $h_k$'s are health attributes of the respondent (head of household) or other household members, that are presumed to be associated with, or induced by, air pollution (with the exception of smoking which itself induces similar symptoms). The health variables include coughing, wheezing, sputum emission and shortness of breath; diseases refer to asthma, bronchitis, pneumonia, and other lower respiratory tract diseases. As already indicated, y stands for the perceived level of neighborhood pollution. Respondents were requested to indicate this on a severity scale of 1 to 6.[16]

To estimate the share equation (6) we employed a procedure that combines iterative minimization methods for non-linear regression with OLS estimation, imposing the symmetry and adding-up restrictions. All variables were normalized through division by their respective sample mean. Table 6 displays the parameter estimates. Inserting the parameter estimates from the budget share (5) into the indirect utility function (4), and

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[15] It should be noted that the majority of families belong to one of several quasi-public health insurance schemes, and do not pay directly for medical services. However, paying for private medical visits and medications in order to obtain faster, and often better quality treatment is quite common, especially with sick children. Information on these extra costs, available from the survey, was also used in deriving expenditure levels. It can therefore be surmised that the number of clinic visits, in and by itself, reflects an opportunity cost of time in obtaining medical treatment, even though no immediate payment is necessarily associated with it.

[16] While the perceived level of pollution may directly affect the demand for housing and hence values, its impact upon medical expenditure is indirect; the latter, are affected by actual pollution levels. However, there is a rather high partial correlation between these two measures (r=0.77). On the appropriateness of using perceived rather than actual measures of pollution levels from a psychological perspective, see Zeidner and Shechter (1988). It may be noted that had it been possible to elicit quantitative responses for perceived air quality, it probably would have been possible to use the restricted indirect utility function as suggested by Diewert (1978).

evaluating its partial derivatives with respect to prices, income, and the public good, at the point of means, it can be shown that $\partial V/\partial P_i^* < 0$ (i=1,2), $\partial V/\partial M > 0$, and $\partial V/\partial y > 0$, as expected. utility decreases with a rise in the (normalized) prices of housing and medical services, and rises with the level of money expenditure on the two market goods and with the level of air quality. It can also be shown that the function possesses the correct signs for the second derivatives.

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Table 6
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4.3 Welfare change measures

The expenditure function takes on the form:

$$\mu = \Bigg\{-\Big[a_1+a_2+(\ln P_1)(b_1+b_2)+(\ln P_2)(b_2+b_3)\Big] \pm \Bigg\{\Big[a_1+a_2+(\ln P_1)(b_1+b_2)+(\ln P_2)(b_2+b_3)\Big]^2 - (2b_1+4b_2+2b_3)\Big[\alpha+(\ln P_1)(a_1+d_1)+(\ln P_2)(a_2+d_2)+\tfrac{1}{2}b_1(\ln P_1)^2 + b_2\ln P_1\ln P_2 + \tfrac{1}{2}b_3(\ln P_2)^2 - \ln V\Big]\Bigg\}^{\frac{1}{2}}\Bigg\} \left[\frac{1}{b_1+2b_2+b_3}\right] \qquad (7)$$

where $\mu=\ln M$, $\alpha = \alpha_0+1+\ln y$, $a_1 = \alpha_1+\gamma_1\ln y$, $a_2 = \alpha_2+\gamma_2\ln y$, $b_1 = \beta_{11}+\delta_{11}\ln y$, $b_2 = \beta_{12}+\delta_{12}\ln y$, $b_3 = \beta_{22}+\delta_{22}\ln y$, $d_1 = \sum_{k=1}^{s}\phi_{1k}h_k$, and $d_2 = \sum_{k=1}^{s}\phi_{2k}h_k$.

Given the parameter estimates from eq. (6), CS and ES values (eqs. 1 and 2) - associated with a ±50% shift from the baseline air quality levels - can be calculated using eq. (7). These calculations yielded annual payments of 2.33 end 105.10 NIS, respectively, per household. Because the expenditure function is nonlinear, the values which have Just been calculated are equivalent to evaluating a function of the form $f(\overline{x})$, which generally would not yield the same values obtained from evaluating $\overline{f(x)}$ instead. Thus, we have also computed the means of individual valuations by calculating the two welfare measures for each household, using the relevant attributes for that household. These calculations yielded the following mean valuations for the sample of households: $WTP^c$ = 9.81 NIS (S = 38.3), and $WTP^e$ = 73.25 (s = 106.2). As noted above, and shown by Loehman (1986), there is no a priori theoretical Justification for expecting either EV>CV or the reverse; both cases are consistent with theory, and the direction of the inequality sign depends on the shape of the indifference curves.

The expenditure function for utility kept at a level associated with the initial (sample mean) air quality is shown in Figure 3 (on a logarithmic scale). The corresponding Bradford-type bid curves, showing WTP as a function of y for utility held at the initial level (CS), and at the final level (ES), are drawn in Figure 4 (marked $WTP^c$ and $WTP^e$, respectively). It can be seen from Figure 3 that the marginal bid function, or the compensated demand for the public good (the partial derivative of the expenditure function with respect to the public good, for given market good prices and utility level), would be negatively sloped.

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Figure 3

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Figure 4

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## 5. INDIRECT VALUATION: HEALTH PRODUCTION APPROACH

### 5.1 Introduction

The household health production is the basis of a valuation approach in which the benefits from a public good, viz., environmental quality, are assessed indirectly through household optimizing behavior with respect to the production (and consumption) of good health. This health "capital" is an argument in the utility function, along with other goods and services. The production of health contributes to utility on two counts: (1) Reducing expenditures on health care services, which otherwise would have decreased the amount of income available for spending on utility-enhancing goods and **services**[17]; (2) Diminishing the impact on utility through income reduction caused by work-loss days, or increasing income through productivity gains. In this framework, one would also have to consider decisions concerning the money time spent on preventive or averting activities. These contribute directly to the production of health stock (but also reduce the budget available for goods and services). Of course. the total effect on utility amounts to a WTP valuation of the welfare changes attributable to changes in the quantity of the environmental good.

Several studies have used the health production approach to estimate the value of reducing health risk resulting from air pollution abatement (e.g., Cropper, 1981; Gerking and Stanley, 1986; Harrington and Portney, 1987; Berger, et al., 1987; Dickie and Gerking, 1988). The emphasis has been on the inclusion of preventive expenditure in a utility maximizing framework, and demonstrating the theoretical superiority of this approach compared to the COI approach. The latter overlooks preventive expenditure, namely, the possibility that individuals yield a measure of control over the state of their health, any direct utility losses associated with illness, and the value of bed-day losses of the non-working population (cf., e.g., Cooper and Rice, 1976). It should be noted, however, that in the various empirical applications of the health production approach, the budget-reducing or income-enhancing effects have generally been not explicitly considered, and a fixed budget is assumed. What one is left with is usually a utility maximizing framework where only preventive activities (in addition to medical care and other consumption expenditure) are taken into account (see the empirical sections of the above cited studies).

In this section we outline a model which attempts to provide

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[17] To the extent that the utility derived from consumption of goods and services is in turn affected by health conditions, then reduction of bed days would also be taken into account.

a comprehensive framework for dealing with uncertainty[18] and the dynamic aspects of the health production process. Since we too assume a fixed budget, our approach yields Valuations of the environmental good which do not take into consideration the labor savings component. We only outline the model here (for a full description see Shechter, 1988), and then provide some tentative WTP estimates.

5.2 The model

Assume an individual producing different levels of health depending upon initial health stock, the amount of medical or preventive care consumed, the level of the environmental public good, and socioeconomic attributes. Uncertainty is represented by probabilities of being in an ill or a healthy state, following a first-order Markovian process (Hey and Patel, 1983). Several simplifying assumptions, some quite strong, have been made: (1) The probabilities are a function of the individual's current health state and not affected by age or by past medical history. (2) Two types of health stock related expenditure exist: Preventive care and medical care, where the former is exercised only when the individual is healthy, while the latter is consumed only when he or she is ill.

The health production process is given by:

$$H = \begin{cases} H_h(m_h, y, \sigma) & \text{when healthy} \\ H_s(m_s, y, \sigma) & \text{when ill} \end{cases} \tag{8}$$

$$\frac{\partial H_h}{\partial m_h} > 0 \; ; \; \frac{\partial H_s}{\partial m_s} > 0 \; ; \; \frac{\partial H}{\partial y} > 0 \text{ and } \frac{\partial H}{\partial \sigma} \lesseqgtr 0 \text{ (for h and s)}; \; \frac{\partial^2 H_h}{\partial m_h^2} < 0; \; \frac{\partial^2 H_s}{\partial m_s^2} < 0$$

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[18] A different approach to uncertainty is given by Berger, et al. (1987).

where

H - the individual's health level,

$m_h$ - amount of preventive care consumed,

$m_s$ - amount of medical care consumed,

y - the level of the environmental good,

$\sigma$ - socioeconomic characteristics of the individual.

The budget constraint is:

$$I = \begin{cases} XC_x + m_h \cdot C_h & \text{when healthy} \\ XC_x + m_s \cdot C_s & \text{when ill} \end{cases} \tag{9}$$

where

I - income

X - a composite good which does not affect health,

$C_x$ - the price of X (normalized to $C_x=1$),

$C_h$ - the price of a unit of preventive care,

$C_s$ - the unit price of medical care.

A state-dependent utility function is defined over two goods - the composite good, x, and health , h.

$$U(x;\ h)= \begin{cases} V(x) & \text{when healthy} \\ W(x) & \text{when ill} \end{cases} \tag{10}$$

It is assumed that for any given x, utility in the healthy state is greater than in the illness state, $V(\cdot)>W(\cdot)$, and that the individual is risk averse: $V'>0$, $V''<0$, $W'>0$, and $W''<0$.

For the Markovian process of transition between health states over time the following probabilities have been defined:

P - The probability that an individual who is healthy today will also be healthy in the next period, where $P'(h) > 0$;

1-P - The probability that an individual who is healthy today will be ill in the next period;

Q - The probability that an Individual who is ill today will be healthy in the next period, $Q'(h) > 0$;

1-Q - The probability that an individual who is ill today will also be ill in the next period.

### 5.3 Optimization

The individual is assumed to maximizes lifetime expected utility, allocating the budget among X, $m_h$ and $m_s$, given the health production function and the budget constraint. Expected lifetime utility from T onward is given by

$$\sum_{t=T}^{\infty} \rho^{t-T} U_t(X;H) \tag{11}$$

where $\rho$ is the rate of time preference.

One first solves for the optimal values of X, $m_h$ and $m_s$, subject to the constrains. As noted, these optimal values are time-invariant, implying that all time periods are identical, given the state of the individual' health. Upon totally differentiating the first order condition, it is possible to obtain an expression for the individual's willingness to pay for a change in the level of the environmental good, $\frac{dI}{dy}$, measuring the value at the margin of the public good after all utility-maximizing, consumption adjustments have been made. We omit the details of the derivation (see Shechter, 1988), and give the final expression:

$$\frac{dI}{dy} = \frac{-P'\frac{\partial H_h}{\partial y} - Q'\frac{\partial H_s}{\partial y}}{\frac{P'}{C_h}\frac{\partial H_h}{\partial m_h} - \frac{Q'}{C_s}\frac{\partial H_s}{\partial m_s}} \tag{12}$$

Note that expressions involving utility terms have been factored out, facilitating in principle empirical applications (cf. Gerkings and Stanley, 1986; Berger, et al., 1987).

We would generally expect $\frac{dI}{dy}$ to be negative, because a decrease in air quality would require some compensation for utility (at the optimal level) to remain unchanged. The change would increase health risks and welfare losses, even after the individual makes an attempt to offset this increase, at least partially (depending on one's preferences), through some budget reallocations entailing, among others, more spending on preventive or medical care. For $\frac{dI}{dy}<0$, the following conditions, - which seem reasonable - should simultaneously be satisfied:

(a) W'>V' -- the marginal utility of income of a non-healthy Individual is higher than that of a healthy individual.

(b) $P'\frac{\partial H_h}{\partial y} < Q'\frac{\partial H_s}{\partial y}$

That is, the change in the probability of being healthy in the next period due to a change in air quality is higher for an ill person than for a healthy one.

In order to apply the model to available data, an additional simplifying assumption was made, namely that there is no distinction between medical and preventive activities, and both having the same unit price. Thus:

$$m_h = m_s, \quad \left(\frac{\partial H}{\partial m_s} = \frac{\partial H}{\partial m_h} = \frac{\partial H}{\partial m}\right), \quad C_h = C_s = C, \quad \frac{\partial H_h}{\partial y} = \frac{\partial H_s}{\partial y}.$$

From this it follow that

$$\frac{dI}{dy} = - \frac{\left[\frac{\partial H}{\partial y}\right] (P'-Q')}{\frac{1}{C}\frac{\partial H}{\partial m} \quad (P'-Q')} = - \left[ \frac{\frac{\partial H}{\partial y}}{\frac{\partial H}{\partial m}} C \right] \qquad (13)$$

The simplifying assumptions eliminate the rationale for the transition probabilities, since no distinction is effectively made between two states of health. It is immediately seen that these simplifying assumptions render the results identical with those obtained by Gerkings and Stanley (1986) and Berger, et al. (1987). It is also readily seen that the amount of money an individual is willing to substitute for a given improvement of air quality increases as with health risks of exposure to pollution **($\partial H/\partial y$).** Similarly, it increases as the efficacy of health or preventive care services **($\partial H/\partial m$)** diminishes.

5.4 WTP Estimates

The survey did not yield workable data on preventive care expenditures of households. We did obtain qualitative statements regarding “active” and “passive” responses to air pollution. Active responses entailed a greater expenditure of time and effort, and Included activities such as participating in demonstrations against air pollution, writing protest letters, shutting windows, etc. About 16% of the sample Indicated. that they at one time or another engaged in such active behavior, but it would be very difficult to assign a monetary value to those activities. We did not ask any questions regarding purchases of home air conditioners (car air conditioners are relatively rare), because - given the climate of the country - these would be purchased almost solely to relieve the harsh effects of summer heat and humidity. We also attempted to find out whether pollution affected residential mobility, but only 1.7% of respondents who had moved in the previous two years indicated that this was the major reason for changing residences. (A similar percentage indicated noise pollution as the prime reason for moving.) Of course, we have no idea how many former residents of Haifa have migrated out of the region for this reason. All of this left us with no alternative but to assume that only medical care budget reallocations matter in households' health production decisions.

Rewriting eq. (13) as $(\partial m/\partial H)$ C $(\partial H/\partial y)$,[19] we estimated the first term using conditional probabilities. First, specifying a logit model, we estimated the probability of at least one doctor visit during a two-week recall period prior to the interview, for each of three health states: h=0, healthy; h=1, having symptoms; h=2, having symptoms and respiratory diseases. All the other explanatory variables (except AV14, see below) are dichotomous. Medical services covered here include doctor visits (mostly at primary health clinics belonging to one of the health maintenance organizations, the so-called "sick funds") of the interviewee, spouse, and children.[20] Logit regressions were estimated for doctor visits, including private consultations (separately for respondents, spouses, and children).

Table 7

The variable representing pollution, AV14, Indicates measured

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[19] Assuming the health production function enables us to write express it in terms of its inverse, m(H,y), namely, that the conditions of the implicit function theorem hold.

[20] In Israel almost all medical services are publicly provided, then, unless they actually sought private medical services, people are usually not fully informed of the out-of-pocket expanses. However, it is reasonable to expect that they would take cognizance of the time and psychological costs involved in a clinic visit or a hospital stay. These may bear some relationship to the real economic costs of providing the service. Children visits to a physician refer to at least one visit by at least one child from the respondent's family, since children were not individually identified in the questions relating to health conditions. See also footnote 15 above.

(actual or extrapolated) $SO_2$ concentrate ions (in ppb).[21] The variable AV14 is significant in every regression.[22] Respondents with respiratory system problems are more inclined to seek medical help, and so are females, respondents with no children in the 0-18 age group (probably a proxy for older respondents), and those of Asian-North African origin (may also be related to belonging to a lower income group). The results for spouses and children were similar, with AV14 figuring in all of them, but they have not been used here.

Next, we specified a multinomial logit model to describe the relationship between health state and pollution levels, where $p_1 = prob(h \geq 1)$, and $p_2 = prob(h=2)$. The results are given in Table 8. Again, as expected from the discussion in Section 2 above, AV14 is highly significant. The coefficients of the socioeconomic variables have also the expected sign.

Table 8

Viewing the medical care use probabilities as conditional probabilities given one's health state, we have calculated the change - at mean values of the other explanatory variables - of reducing mean AV14 by 50% (going from $y_0$ to $y_1$. Viz.,

$$\Sigma_i \text{ p(doctor visit in past 2 weeks / } h_i) \times p(h_i / y{=}y_0)$$

21 Since pollution data is measured only at a few points in the Haifa metropolitan region (and only $SO_2$ on a continuous basis), it was necessary to extrapolate ambient concentrations for the rest of the survey neighborhoods using an *ad hoc* dispersion model. Average concentrations were computed for two-week periods preceding the date of any given interview. The two-week averages are based on half-hour concentration readings.

22 An alternative set of regressions was run with the variable MAX14, representing maximum daily concentration for the preceding two-week period, but AV14 turned out to be a better predictor.

$$- \Sigma_i \; p(\text{doctor visit in past 2 weeks} \,/\, h_i) \times p(h_i / y=y_1),\; i=0,1,2$$

The decrease amounted to 2.26% percentage points, or about 8% from present usage levels. Converting this result to expected number of annual visits, and multiplying by C, the cost per visit of NIS 30,[23] yields a *rough approximation* of WTP of NIS 32.43.

Of course, this figure is an underestimate: (a) It does not include visits of spouse and children; (b) it is based on a question which asked whether there was at *least* one visit during the preceding two-week recall period, but did not ask for the actual number of visits; (c) it does not include hospitalization cost[24] or medication costs[25] ; (d) finally, as explained above, it overlooks the labor cost savings.

An altogether different question is associated with the nature of medical care services in a country like Israel, where most of the population Is covered by one form or another of a subsidized quasi-public health insurance scheme. In this sense individuals do not have to make budget reallocation adjustment in the way assumed in the model. However, as remarked above. time and Inconvenience associated with a visit to a primary health clinic might nevertheless be playing a major role, not much different from that of money expenditures. This of course is another major drawback of the empirical results, but we surmise that CVM valuations may have well been similarly affected.

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[23] Although no statistics are available, we believe this figure to be close, though somewhat lower than the corresponding cost of a private consultation visit to a general practitioner.

[24] Respondents were also asked about hospitalization during the 12 month period preceding the interview for illnesses connected with the respiratory system, but the number of responses was too small for any meaningful analysis.

[25] The expected decrease in the probability of obtaining medication resulting from pollution reduction, has been calculated to reach 17% approximately (a decrease from p=0.113 to 0.094).

## 6. COST OF ILLNESS (COI) VALUATIONS

### 6.1 Consumption of Medical Services and Bed Day Losses

The COI approach normally covers direct (expenditures on medical services) and indirect (income reduction due to work day and productivity losses). As observed above, given that work loss has been neglected in the household production model, we have made an attempt to estimate these losses. Since individuals would not directly suffer the consequences of work loss days because of the almost universal coverage by employer-paid sick-day leave, this cost is distinctly a social cost. We would not expect it to be expressed through *individual* WTP valuations.

A binary response model was used to analyze bed days during the two week recall period. The response variable, STY, was defined as follows:

$$STY = \begin{cases} 1 & \text{if respondent missed one or more days} \\ 0 & \text{otherwise.} \end{cases}$$

Although our sample was large (n=954), the results are nevertheless based on a *relatively* small number of observations, since only 65 cases were respondents who reported that they were absent from work for at least one day during the fortnight. A model was fitted with both socioeconomic and health attributes, using backwards elimination to fit the logistic regression. The estimated equation is given in Table 9.

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Table 9

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When AV14 is reduced by 50%, the probability of at least one bed day decreases from p=0.051 to 0.041, a drop of 18 percent. Work loss days at present pollution levels constitute about 1.85% of all work days. The total expected annual savings in number of work loss days due to pollution abatement, $\Delta L$ (assuming 300 working days per year), is given by $\Delta L = E \times 300 \times 1.85 \times \Delta p$, where E is the number of employed persons (above age 15) in the metropolitan region, and $\Delta p = 0.18$. A similar calculation was performed for the *non-working* persons in the sample. The weighted mean sample percentage of bed days (corresponding to the working group's work loss days) is 3.57.

Assigning a money value to these savings, would of course vary with the specific assumptions relevant in each case. The present calculations were based on 1987 gross wages per salaried employee, including social benefits, of NIS 1,832 per month, or $1,221 (Central Bureau of Statistics, Statistical Monthly, April, 1988). At this wage rate, the money value of the savings would total NIS 10 million per year for the working group. For illustrative purposes, if we also value a day of a non-working person at 1/2 that of a working person, an additional savings of almost NIS 8.5 million would be achieved, for a total of NIS 18.5 million. On a *per household* level, the expected savings would amount to about NIS 185.0

## 7. COMPARATIVE EVALUATIONS

### 7.1 CVM vs. Indirect Approaches

Several writers (e.g., Randall, 1987; Mitchell and Carson, 1989) have noted that the CVM approach deals with *ex ante* valuations, while the indirect approaches are usually associated with *ex post* valuations. This implies that one therefore should *not* expect to necessarily obtain close estimates in the two approaches; but the opposite is not necessarily true, either. Reliability of either approach *(which* one would supposedly be an empirical question) might be questioned, however, if results derived from the *same* set of observations turn out to be vastly different. Hence, a comparison of the results from the various approaches should be illuminating. Table 10 summarizes the values obtained under the different approaches.

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Table 10

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The closeness of the valuations is quite encouraging. Although the indirect approaches cover all respondents, including zero bidders, it is assumed that the this approach yields true valuations of protest bidders as well, and hence, the comparison should be made with the true bidders (non zero and true zero) of the corresponding CVM experiments (Tables 3 and 4). It should be noted especially that the mean values of individual household valuations in the two approaches are within the same order of magnitude (NIS 9.8 vs. 34.5 for $WTP^c$, and 73.3 vs. 68.6 for $WTP^e$).

7.2 Health Production, COI and CVM valuations

Although very tenuous assumptions were made in applying the household health production approach, one observes the closeness of the results to the CVM valuations. Since the model measures responses to reduction in pollution, the appropriate comparison is with the $WTP^c$ valuations. Indeed, if other health and preventive care components were added, the results of the $WTP^c$ comparisons could have turned out to be even closer.

Theoretically, the cost of illness estimates should have at best provided a lower bound on WTP valuations. But this should not have been the case in the present study, given that COI estimates refer to *social* rather than individual WTP, and include components which do not figure directly in the individual's decision making process. Thus, households do not directly bear all the cost of air pollution damages. They are covered by medical insurance, and do not bear the full cost of medical services. Part of the premium is paid by employers and, furthermore, medical services are subsidized by the government. In addition, paid sick-leave is almost universal for salaried workers. But, moreover, people clearly do not possess the kind of dose-response information which would have enabled them to fully assess the economic impact of exposure and disease. These facts would necessarily be reflected in WTP valuations. One should also note that cost of illness estimates are probably more susceptible that the others to data "manipulation". The results are sensitive to what we assume about the appropriate values for work loss of employed and unemployed individuals, the ratio between privately purchased and publicly provided prescriptions, and the cost of physician visits, etc.

In a certain sense, one might speculate that CVM responses represent willingness to pay to reduce the direct *disutility* associated with morbidity, plus maybe the aesthetic disutility of air pollution. Namely, CVM valuations are essentially the psychological costs associated with pollution. Indeed, results presented elsewhere (Zeidner and Shechter, 1988) indicate that WTP is sensitive to anger and anxiety caused by perceived exposure to air pollution. If this were indeed the case, then the CVM valuations, or at least part of them, should be *added* to cost of illness valuations!

### 7.3 Some concluding comments

Within the framework of a study dealing with the valuation of benefits from pollution abatement, several approaches were investigated. A notable feature of the present study has been the use of the an *identical* data base - households, their attributes and responses - in all three approaches. While contingent valuation relies exclusively on direct question techniques, so that survey data are a *sine qua non,* market demand systems are normally estimated from aggregate, secondary market data. In this study, however, the same *primary* data base was used. Valid comparable valuations pertaining to the same set of households were thus obtained. Since all approaches are presumed to measure the same thing(s), one should a *priori* expect the results to be close.

In this vein, we view the results as rather encouraging and believe that they provide further impetus for the use of CVM. Of course, improved statistics on health and preventive care should offer an improved basis for alternative, indirect appaoraches.

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